ENTILATION

FOR

ELLINGS
RURAL SCHOOLS
AND STABLES

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DWELLINGS, RURAL SCHOOLS AND STABLES

BY

F. H. KING

Formerly Professor of Agricultural Physics in the University of Wisconsin. Author of "The Soil;" "Irrigation and Drainage;" "Physics of Agriculture."

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PHYSICS OF AGRICULTURE

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PREFACE

In the preparation of this brief treatise the aim has been to reach parents, teachers and school officers of rural and other elementary schools, and the owners and caretakers of all classes of live stock, and lay before them the foundation facts and principles underlying the growing and imperative demand for a more nearly adequate supply of pure air than is being continuously maintained in the vast majority of homes, offices and stables today.

In presenting the subject the effort has been to make the treatment suggestive to teachers, introducing lines of simple experimentation and arithmetical calculations, so that they may more surely enlist the attention and cooperation of their community in the immediately practical aspects of the subject. It is hoped, too, that all owners and caretakers of live stock will find the treatment of stable ventilation sufficiently explicit and illustrative to enable them to readily and effectively solve their own problems.

In applying the principles used in stable ventilation to dwellings, offices and school-houses, where mechanical appliances or hot air furnaces are not used, we are convinced that there are no practical difficulties in the way and that when such a system of ventilation is combined with the warming as suggested it will be found thoroughly efficient. In the effort to be brief, and yet have the presentation sufficiently fundamental and explicit so as not to mislead, it has been necessary, in the treatment of dwellings and schools, to omit details, yet it is hoped enough has been given so that with the aid of builders and local architects installations may be readily made.

F. H. King.

Madison, Wisconsin.
Nov. 23, 1908.

"And did it occur to you that here, too, was another bellows feeding air into another forge, keeping the fire of life áglow and timing its intensity to the work to be done?"—*Page 1.*

INTRODUCTION

Have you stood in a smithy's door and watched the cold bar of iron mount by quick steps to a white heat as the strong arm on the bellows compelled fresh air through the bed of coals on the forge? Did you reflect that that intermittent air current contributed more pounds avoirdupois to the generation of the heat than did the coal, in the ratio of about 8 to 3? Did you note the capacity of the huge bellows, the powerful lever with which it was worked, the length of the strokes and the weight which the smith threw onto the bellows to feed sufficient air to his forge? Did you note the rythmical rise and fall of the smith's deep chest as he moved about his work? How the heaving quickened and deepened as the blows from the hammer fell more swiftly and with greater force upon the shaping piece? And did it occur to you that here, too, was another bellows, feeding air into another forge, keeping the fire of life aglow and timing its intensity to the work to be done?

Did you observe how thoroughly the smith kept drawing up over his fire a blanket of cinders and coal, that the heat should be retained where the work was being done and that as little as possible should be wasted? And did you realize how much more this greater economy made the action of the bellows necessary to carry sufficient air to the exact place where it must be used? And do you realize with what consumate economy all the forges of life, whether of man, beast, bird or bee, have been housed in from the cold and are continuously fanned, whether waking or asleep, by automatic bellows, thus generating the maximum of energy with the minimum of fuel and of labor?

Now when the best results from the forge demand a continuous action of the bellows, feeding in more than 11 pounds of pure air through the fire for each pound of coal burned, and when the health and best action of the smith demand more than 20 cubic feet of pure air per hour, what would you think of setting up and operating, in an 8 by 8 room without chimney and with doors and windows closed, such a combination of forge and man during ten consecutive hours, depending for the renewal of air upon such leakage as may take place through walls and ceiling? And yet are not conditions more deplorable than these found in many a sleeping chamber, stable, bee-hive, factory and church? Do we not realize and generally practice in accordance with the fact that closing the drafts in a stove checks the intensity of the fire or extinguishes it altogether? Do we not understand perfectly that the proper action of a stove or of a furnace can only be secured through the effective action of a good chimney? Do we not know most thoroughly that we may go for days without food, and even without water, but that to be deprived of air for only a few minutes results in the greatest distress and may even prove fatal? Have we not felt the oppression which follows the closing of ventilators and windows of a crowded coach for only a minute or two to shut out the smoke while the train passes through a tunnel, and do we not recall how everyone is looking anxiously for the windows and ventilators to be opened the moment the train emerges?

How can it be, then, that today, even in cities where homes are planned by trained architects, little or no thought is given to making special provision for ventilation in the majority of dwellings. First of all, must not the house be cheap, then if it can be warm, light, convenient, commodious and attractive are not these clear gains? If we can cook, wash and iron with gasolene, a blue-flame oil stove, gas or electricity, then may not the expense of one chimney be saved? And if we will heat the house with hot water or with steam may not every room then be as nearly an air tight box as the materials and the mode of construc-

tion makes possible? And with such arrangements may not the work and the warming of the house be done with the least possible expense for fuel? Most certainly, but how about the health and comfort of the family for whom the home was built? Which is better, a close house with but little air, to be breathed and burned over and over again, with langour and irritableness, and perhaps less of service through sickness and a large doctor's bill, or an airy home, full of buoyancy, cheer and health but perhaps a trifle larger bill for coal?

Is it urged that the wind will force air enough through the house and stable even with the closest possible construction? But how about the days and the nights when there is little or no wind? Then the windows may be opened? But who thinks to do this at the right time? Perhaps the one in the family who suffers most from insufficient change of air is too unselfish or too sensitive lest some one else would be disturbed by opening the windows, or perhaps the herdsman has too little thought for the animals in the stable to take the necessary trouble at the proper time. Clearly, if an abundant change of air is needful, a flow should be continuous and sufficient at all times, whether we are awake or asleep, and whether attention is given to it or not. That an abundant change of air in the house or in the stable is needful there can be no doubt, and that this cannot take place unless proper arrangements are provided for it is likewise evident.

NATURE'S PROVISION FOR VENTILATION OF BODY-TISSUES.

So great, so imperative and so constant is the need of fresh air in the maintenance of vigorous bodily functions that the delicate lining membrane of the lungs of an ordinary man, in contact with which air is brought and through which all the blood of the body circulates, were it spread out in a continuous sheet, would measure no less than 236 square feet, enough to cover the sides, floor and ceiling of

a room more than 6 by 6 by 6 feet, and that of a 1000-pound cow would similarly cover a room 11 by 11 by 11 feet.

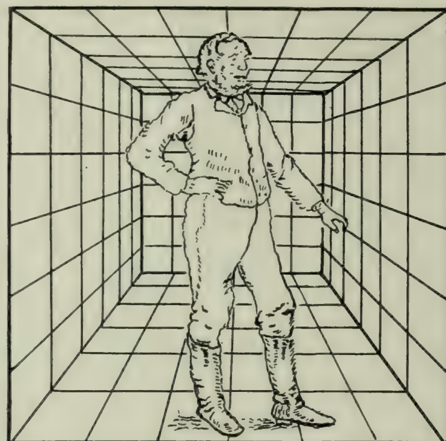


Fig. 2.—The area of this room, walls, floor and ceiling, 6 by 6 by 6 feet, represents the amount of surface in the lungs of an ordinary man through which all the blood of the body passes about twice every minute, to be brought close to the air which is changed by the act of breathing 15 to 20 times per minute.

Such enormous surfaces as 236 square feet of delicate lining membrane, in the lungs of man, and of 1,500 square feet in those of the cow, may seem impossible. That this is not so may be understood when it is said that a box one foot on each side has an inside surface of six square feet. Pass a partition through the center of this box each of the three ways. The eight chambers so formed have double the aggregate inside surface of the original box, or twelve square feet per cubic foot of space. By passing ten planes through the box in each of the three ways we would increase the inside surface ten-fold, giving it 60 square feet, and so 40 such partitions passing in each of the three directions would increase the inside area 40-fold, giving just about the lung surface for man, and yet each of the 64,000 small chambers so formed, three-tenths of an inch on a side, would be very much larger than the actual air-cells in the lungs. In the

box represented in Fig. 3, subdivided by 40 planes passing each way, the small divisions are each one-twelfth of an inch in diameter, easily visible, and the total wall surface formed by them measures no less than 18.5 square feet and about one-twelfth the lung surface of man, thus making it clear how a very large surface may be developed in a small space.

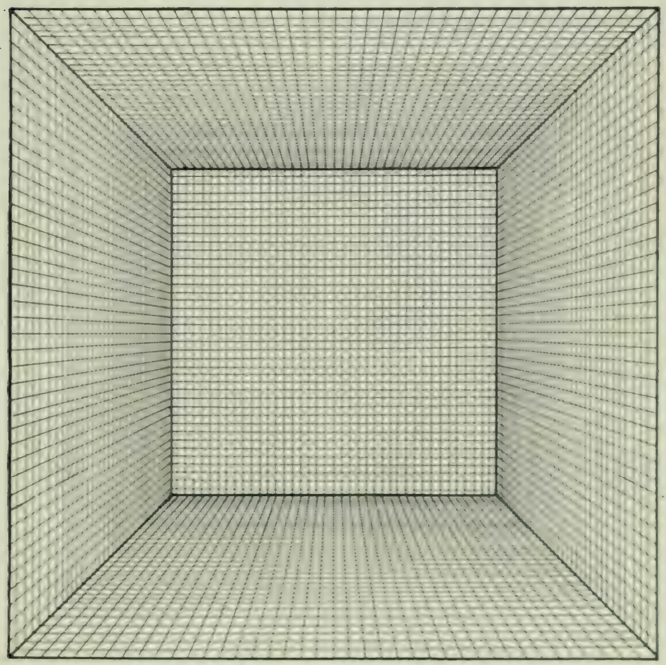


Fig. 3.—A box the size of this drawing, subdivided by as many partitions as are represented by the lines, would form 64,000 chambers having a total wall surface of 18.5 square feet, one-twelfth that in the lungs of an ordinary man.

Now imagine blood flowing steadily through a close network of capillaries within all the partitions in this box, and at the same time, by a bellows-like action, that the air is drawn into and forced out of it 15 to 20 times every

minute, and you have, then, a fairly truthful illustration of the principle underlying the mechanism by which the blood of the body is brought continuously into close touch with a fresh supply of air. The blood vessels, bringing all of the blood of the body to the lungs, subdivide and spread out until they expose to the air in the air-cells some 236 square feet of blood surface, flowing in the thinnest possible streams almost in touch with air on two sides, which is being renovated by 15 to 20 respirations every minute, while the powerful action of the heart drives the whole blood of the body over this large surface once every 20 to 40 seconds.

There is another remarkable feature in the wonderful mechanism which nature has found necessary to make sure that oxygen shall be brought to and carbon dioxide removed from the body tissues as rapidly as is needful. The water of the blood, although comprising 80 per cent of its weight, does not have a sufficiently strong absorbing power to permit it to take up oxygen in the lungs, exchanging it for carbon dioxide in the tissues, as rapidly as is needful and hence more than half the volume of the blood is put into the form of circular, cracker-shaped disks called the red corpuscles, giving its characteristic color. These corpuscles strongly absorb oxygen when in the lungs and exchange it for carbon dioxide when in the tissues, thus acting like so many conveying buckets which are continuously loading and unloading with each round trip and yet without stopping. Moreover, to make sure that each one of these carriers shall be brought in touch with air before it can return to the body, the diameters of the capillaries are made so small that these absorbing disks are compelled to pass through them almost in single file with both faces almost continuously in touch with the lining membrane of adjacent air cells, thus insuring ample opportunity for the unloading of the carbon dioxide brought from the tissues, and for the reloading with oxygen to be carried back.

There is represented on the right in Fig. 4 a face view with a cross-section of one of these oxygen and carbon diox-

ide carriers magnified some 2,650 diameters, and on the left a single capillary with the corpuscles passing through it in single file.

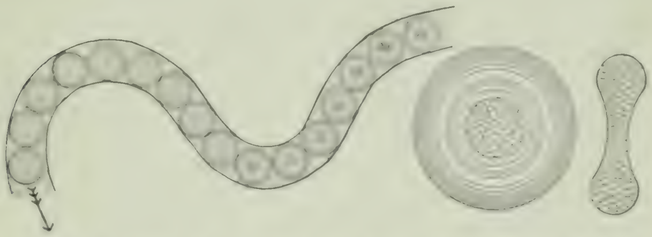


Fig. 4.—Here is seen, on the right, the shape of the oxygen and carbon dioxide carriers in the blood of man, magnified 2,650 diameters and, on the left, a line of them passing single file through a capillary, magnified about 600 diameters.

These carriers of oxygen-food to the body tissues and of carbon-dioxide-waste from them, although so extremely minute, are yet so numerous that the total surface of the corpuscles in the blood of an ordinary vigorous healthy man measures no less than 49,000 square feet, or more than a full acre. Think of the heart, with its 70-odd strokes per minute, sending more than a full acre of bucket faces through the 236 square feet of partition surface in the ventilation chamber of the body once every 20 to 40 seconds, and the air of this chamber changed 15 to 20 times every minute! Nor is this the whole story of the structural arrangements in the mechanism of breathing by which the body tissues shall be fed oxygen and freed from carbon-dioxide-waste, for it is at once clear that the flattened shape of the blood disks gives to them not only the largest absorbing surface but at the same time it provides the shortest possible distance over which these gases must travel to enter and leave the tissues, which must take place by the only available but peculiarly slow process of diffusion.

Everything, therefore, points to the most imperative need of a thorough ventilation of the body tissues. But when we are brought to realize how superlatively efficient this mech-

anism for breathing is we can never afford to forget that it grew into its marvelous efficiency unhampered by any of the restrictions or constrictions imposed by fashion, and when all of the breathing was done in the pure free air of field and forest. Nature has provided a very large margin of safety in this, as in other matters meaning life or death to organisms which are the present survivors of uncounted generations which have come and gone. For such as are content to bestow their affections upon pug dogs while they give their lives to the amusement of a brotherhood entertaining if possible less lofty aims in life perhaps the world need not be concerned; but for those who project their lives into the future may God and all the forces which conspire to better living do everything possible to make deep breathing easier and more certain and to maintain a standard of purity of air in the home and in the stable which approaches closely that in the open field. It is along such lines of the fullest utilization of our natural resources, even more than to the husbanding of them, that we need to look if a race shall be perpetuated capable of highest civilization and which will be lead on by higher ideals. How can we hope to combat disease, maintain and transmit bodily vigor, when the very breath of life is shut out of our bodies by thoughtless false standards of dress and from our homes and stables by lack of sufficient thought given to proper construction?

AMOUNT OF AIR REQUIRED FOR A DAILY RATION.

The complete consumption of a pound of hay or of grain, in the body of an animal, converting it into carbon dioxide and water, would require the same amount of oxygen as though it were burned in a stove or on the grate of an engine boiler. Speaking in approximate round numbers the burning of a pound of hard coal requires all of the oxygen carried in some 11 pounds, or 136 cubic feet, of air and the burning of one pound of hay requires all the oxygen in some 5 pounds or 62 cubic feet. But when rapid and com-

plete combustion takes place not all of the oxygen in the air can be consumed and hence much more than 136 cubic feet of air per pound of coal, and than 62 cubic feet per pound of hay, must pass through the fire box for each pound of material consumed. Moreover it is important to keep in mind that air is as much a part of the fuel which produces the fire as is the coal or the wood, indeed, even more so when considered pound for pound. And so is the air an animal breathes as much an indispensable part of the food it consumes as is the hay or the grain eaten. In the furnace neither can burn without the other and so, within the animal body, neither assimilation of food nor generation of energy can take place without the consumption of a proportionate amount of air. When an engine is being crowded to its full capacity in the generation of power not only must the stoking be more rapid but the drafts also must be opened wider that more air may pass through the fire; and so it is with an animal when doing work, no matter of what kind, it must breath more deeply or more frequently. We realize this clearly in our own case and we see it in the horse, the ox or the dog, when they are in violent exercise. Even in the case of the heavy feeding of animals for the production of milk or of flesh proportionately more air must be breathed, and hence when animals are closely housed under these conditions more air should pass through the stable each day.

The amount of pure air which must be breathed by different animals during 24 hours, in order to supply the oxygen needed, computed from Colin's table, is given below:

Amount of air breathed by different animals.

Per hour.		Per 24 hours.		
	cu. ft.	lbs.	cu. ft.	Volume.
Horse	141.7	272	3401	15 x 15 x 15 ft.
Cow	116.8	224	2804	14 x 14 x 14 ft.
Pig	46.0	89	1103	10 x 10 x 10 ft.
Sheep	30.2	58	726	9 x 9 x 9 ft.
Man	17.7	34	425	8 x 8 x 8 ft.
Hen	1.2	2	29	3 x 3 x 3 ft.

From this table it appears that a horse must draw into and force out of his lungs, on the average, each hour, some 142 cubic feet of air, the cow 117, the pig 46, the sheep 30 and the man 18 cubic feet. These volumes are represented in Fig. 5.

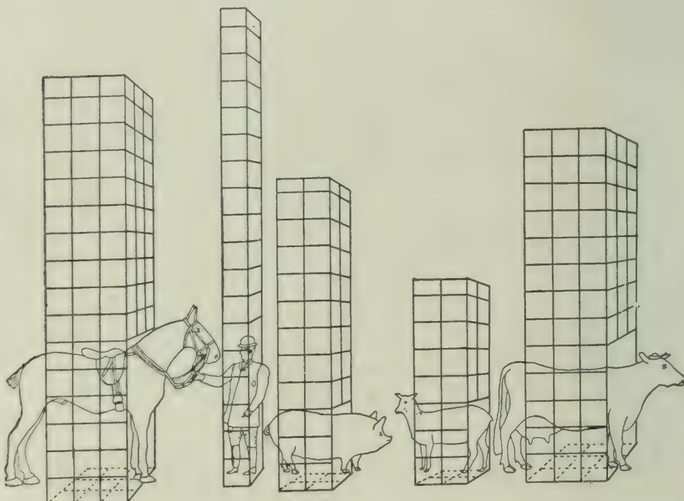


Fig. 5.—Here each small square in the illustration represents one foot and each pile of cubes the volume of air breathed each hour, which should be nearly pure.

If it were necessary to supply air to our stock as we do water the horse would require continuously 7 full pails per minute; the cow, 6; the pig, 2.3, and the sheep, 1.5 full pails of air, and these are the amounts required when it is supplied pure and fresh with each respiration, as would occur out of doors where there is a free air movement and where the air thrown off from the lungs is at once borne away by the winds. Inside a dwelling or stable the conditions would be very different unless some means were provided to maintain a constant change of air at the proper rate.

AIR ONCE BREATHED HAS LOST MUCH OF ITS SUSTAINING POWER.

Air once breathed has lost much of its food value or sustaining power and, impossible as it may seem, we have known horses to suffer from breathing impoverished air when plowing in the open field. This may occur where three horses driven abreast have their heads close and so directed that the middle animal is compelled to draw his supply of air from that thrown out by the other two, and the exhaustion or fatigue of the center horse can often be made noticeably less when a "spreader" or the habit of driving requires the outside animals to breathe straight in front or a little outward. Three heavy horses at hard labor on the plow or harvester draw so much air and reduce its feeding value to such an extent that when the outer horses are permitted to travel a little in advance and at the same time incline their heads in, the center animal is placed at a great disadvantage in being compelled to breathe partly exhausted and otherwise vitiated air, for the case is like feeding the firebox of one engine from the smokestacks of two others. So, too, when a large number of sheep are driven long distances in a closely huddled flock much discomfort results from their being compelled to breathe exhausted air.

Fig. 6.—The air blown across one coal increases the glow.

Everyone has observed that of two glowing coals in the open air the one which has a strong current forced across it burns more rapidly and with a more intense glow. Why is this? Clearly because one has a more rapid change of air, is better ventilated, even though both may be out of doors. Immediately about the burning coal the oxygen of

the air is both partly exhausted and diluted, and the current drives the used air away, bringing fresh air instead. And so ventilation, even out of doors, may be helpful. The lamp without a chimney gives little light and smokes badly but the flame surrounded with a chimney, which seemingly shuts off the free access of air, burns much better and simply because it gets a more rapid change of air. The chimney compels a stream to flow rapidly close to the flame and thus is swept away the used air while a fresh supply takes its place. And so, the lamp, the stove, the engine and the forge, whether in an enclosure or out of doors, must have a mechanism securing a continuous forced change of air; and the respiratory movements of every air-breathing animal tell of the same imperative need. And yet, dwellings and stables are planned, adopting increasingly close construction, allowing ventilation to be brought about incidentally as it may, without special provision. Only last summer in conversation with a New York City architect it appeared that he had recently completed a residence in cement concrete and was much surprised to find that the fireplace would invariably smoke unless a door or window of the room was open.

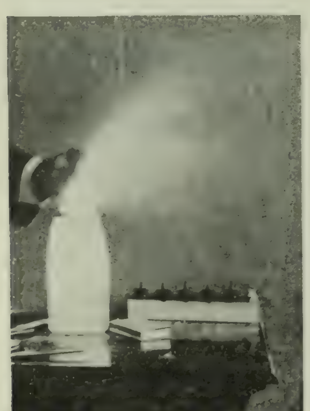


Fig. 7.—Magnesium ribbon burning in ordinary air.

Here is perhaps a more striking demonstration of the need of ventilation and of the fact that air once breathed has lost in sustaining power. In the illustration, Fig. 7, from a photograph, a coil of magnesium ribbon is shown burning in ordinary air supplied by convection currents through the open mouth of a two-quart Mason jar. The intense light which fills the jar and the cloud of white smoke escaping above show how strong is the burning; while in Fig. 8 is shown

a similar piece of the same ribbon burning in the same jar, but here supplied with air from the lungs, conveyed through the rubber tube. Very markedly less intense is the burning and the light produced in this case, and far less is the cloud of smoke. It is of course the diminished volume per cent of oxygen carried by the respired air which causes the difference in the intensity of burning, for the rate of change of air is greater in this case.

Fig. 8.—Magnesium ribbon burning in respired air.

The composition of pure dry air and of air carrying 75 per cent of its saturated volume of moisture, deduced from data of Clarke published in 1908 from the most recent and authoritative determinations, are given in the next table:

Composition of the Atmosphere.

	Volume per cent.	Cubic inches per cubic foot.
Dry air:		
Carbon dioxide	.0292	.506
Oxygen	20.941	361.860
Nitrogen and other gases	79.030	1365.634
Air, humidity 75 per cent:		
Carbon dioxide	.028	.484
Oxygen	20.582	355.657
Nitrogen and other gases	77.677	1342.256
Moisture	1.713	29.603

On the average, in the case of man, it is found that once respired air has lost oxygen to the extent of 4.78 volume per cent. It has acquired 4.35 volume per cent of carbon dioxide and has become saturated with moisture at the temperature of the respired air, while its volume has been increased by the expansion due to the rise in temperature. Each of these changes reduces the absolute amount of oxygen which may enter the lungs in a given time when the air is respired again, unless the depth or frequency of breathing is increased.

The changes in composition which come to once breathed air are indicated in the next table, where dry air and that 75 per cent saturated with moisture before breathing are the basis of computation.

Composition of pure air and of that once breathed.

	Pure air, cubic inches per cu. ft.	Airbreathed. cubic inches per cu. ft.	Change, cubic inches
Dry air:			
Oxygen	361.860	265.920	—95.94
Carbon dioxide	.506	72.059	+71.553
Nitrogen and other gases	1365.634	1300.400	—65.234
Moisture	....	89.638	+89.638
Air, humidity 75 per cent:			
Oxygen	355.657	264.330	—91.327
Carbon dioxide	.484	73.232	+72.748
Nitrogen and other gases	1342.256	1300.800	—41.456
Moisture	29.630	89.638	+60.008

Here it is seen that air once breathed may contain, per cubic foot, from 91 to 96 cubic inches less oxygen, more than 70 cubic inches increase in carbon dioxide and, if the air is dry, some 90 cubic inches more of moisture. The oxygen has been decreased from a volume per cent of 20.94 to one of about 15.39, thus leaving it only three-fourths as rich in its essential food element. This reduction of the oxygen content of the air, first by the direct consumption of it and, second, by its dilution through the addition of other ingredients and by expansion due to rise in temperature, must be the main change which reduces its sustaining power. Indeed breathing becomes difficult so soon as

the volume per cent of oxygen in the air has fallen as low as 13, so that breathing the air but twice would carry the volume per cent of oxygen below this limit, indeed as low as 10 per cent if no fresh air were added to it.

Fig. 10.—Candle extinguished in air once breathed.

We have seen with what diminished brilliancy a magnesium ribbon burns in air once breathed. Here is perhaps a more convincing concrete demonstration of the loss of power to support combustion and to sustain bodily functions which characaterizes respired air.

Fig. 9.—Candle burning in pure air.

Using again the two-quart Mason jar, Fig. 9, let a lighted candle be lowered into it. It burns with scarcely diminished intensity, as did the ribbon, for down-going and up-going currents maintain a continuous fresh air supply. Now while the candle is yet burning let a gentle stream of air from the lungs be conveyed to the bottom of the jar, Fig. 10. Gradually, as the jar fills, the flame loses in brilliancy and finally is extinguished. The flame in this case is certainly not blown out by the air current for the candle may be relighted and again

lowered into the jar after removing the tube. The respired air is heavy enough to remain and, as the candle is lowered into it, it will be extinguished, even after the lapse of more than two minutes if the air in the room is still.

Fig. 11.—The respired air tends to remain at the bottom.

Once more let the candle be lighted and lowered into the jar, Fig. 11. Gradually raise the candle as the flame shows signs of going out. Observe that the respired air tends to remain at the bottom, as may be proven by repeatedly lowering the candle, observing that as this is done the flame tends to become extinguished. As the air is forced continually into the jar it becomes gradually filled and the lighted candle has taken the position represented in Fig. 12. But even here, if breathing into the jar is continued, the flame will be extinguished as the out-coming respired air surrounds the candle and shuts off a fresh supply from the flame. Clearly, then, air once breathed is not suitable for respiration unless much diluted with pure air.

Fig. 12.—The flame is extinguished even when held above the mouth of the jar.

A CONTINUOUS FLOW OF AIR IS NECESSARY.

Since once-breathed air is not suitable for respiration until much diluted with that which is pure it follows that into and out of dwellings, schools, churches and stables, so long as they are occupied, must be maintained a sufficient and continuous flow of air to bear away that whose food value has been reduced and to restore an equal volume of that which is pure. Let us again use the two-quart Mason jar, Fig. 9, for another demonstration. With the candle resting on the bottom and the mouth of the jar unobstructed the flame burns with a steady uniform brilliancy. By holding the hand above its mouth a strong ascending current may be distinctly felt, but such a continuous up-going current of air from out the jar can only be possible when an equal countercurrent is maintained and it is this which sustains the flow.

Fig. 13.—The candle in two quarts of air extinguishes itself in 30 seconds.

Now, with the candle still burning in the jar let these in-going and out-going currents be completely stopped by screwing in place the cover of the jar, Fig. 13. With watch in hand it will be found that in even less than 30 seconds the flame is extinguished. Thus it is demonstrated that an ordinary candle spoils for its own use a full gallon of air per minute: 60 gallons per hour; and more than 200 cubic feet per day. Twenty-four such candles would vitiate the air of a room for themselves and for you at the rate of 200 cubic feet per hour. The small portable kerosene oil stove so frequently used to warm rooms demands

more air than twenty-four candles and hence the rate of change in the room for such conditions must much exceed an hourly flow of 200 cubic feet, which is more than 33 cubic feet per minute. As the candle in the Mason jar extinguished itself in 30 seconds where the walls were absolutely air-tight it is clear that in every room and in every stable there must be either unintentional leaks for air to enter and escape or else definitely provided openings; otherwise neither lights nor life could be long maintained.

Fortunately for mankind and for his domestic animals it has not been practicable to build either dwellings or stables even approximately approaching the degree of impenetrability for air possessed by the Mason jar. But both poorly lighted basement dwellings and stables and the old prison walls and dungeon cells have come dangerously near this limit. Air has entered and left dwellings and stables through openings formed by loosely fitting doors and windows, and in varying degrees under the pressure of the wind through the walls themselves. Then too, the oldtime fireplace, the kitchen range and the heating stove have served a sanitary mission of the greatest importance in that they have always compelled a more or less continuous inflow to dwellings of so much fresh air as equalled the outgo through the chimney. But the fireplace, for continuous service, has long since passed. Heating stoves are being replaced by hot water and steam radiators and the air which warms these misses entirely the life-giving functions for it enters only the basement rooms, leaving by the furnace flue, no part of it having served the purpose of ventilation. Even the kitchen stove is being displaced by the oil, gas or gasolene range, deadly from the standpoint of pure air, for they tend simply to revolve large volumes of the air of the room over and over, consuming its oxygen and adding to it all of the products of combustion, for only rarely are they connected with a chimney.

It is of the highest sanitary importance too, in its bearing upon the general health and bodily vigor of the future, to recognize that in the passing of lumber as a building

material and in the substitution therefor of masonry, metal and various filled and painted compositions, both for outside and inside finish of dwellings and stables, we are steadily, surely and rapidly approaching the ability of the fruit jar to exclude fresh air, compelling it to enter only through unavoidable leaks about doors and windows. We are even building flats with windows and doors limited to but one or at most two sides, at the same time piling one over another where the exhausted, fouled and heated air must rise from one to another through ceilings, floor and hallways. The increasing cost of fuel too is leading to the adoption of storm windows and doors for the few provided, to more effectually shut out the wind. It is difficult to imagine more unsanitary conditions from the "fresh air" standpoint than must be associated with a poorly lighted stack of overcrowded flats piled one above another, warmed with steam or hot water, the cooking and lighting done with gas. When every adult needs hourly, as food, scarcely less than 18 cubic feet of the purest air to be found out of doors; when we are making such strenuous efforts to shut this air out of our homes and stables; when so little specific provision is being made to supply air to them at an adequate rate; should we not be surprised rather that the dread "white plague" does not take even more, vast as the number now is. And if we shall ever be successful in driving it from among us must not the battle be waged in every home where the children are yet well and strong, by applying continuously and efficiently the "fresh air treatment," not leaving it to be administered only at the hospital and to those already stricken?

FRESH AIR SUPPLY CERTAIN TO BE INADEQUATE AT TIMES IF DEFINITE PROVISION FOR IT IS NOT MADE.

Where numbers of individuals are sheltered in compartments of reasonable volume and so constructed as to permit of economic warming in severe weather there are certain to be times when the fresh air supply will be inadequate

unless definite provision for such supply is made. Let us again have recourse to positive concrete demonstration. Here is a cylindrical metal chamber, Fig. 14, 18 inches in diameter and 20 inches deep having a cover which seals the chamber air-tight by means of its rim dipping under sweet oil carried in a groove formed about the top. Around the

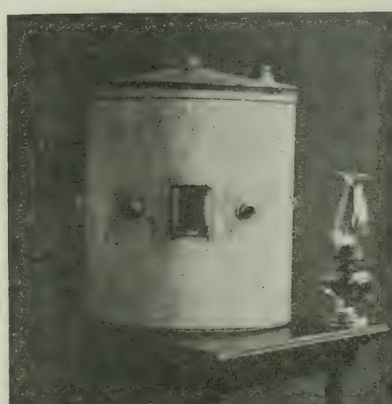


Fig. 14.—A ventilation chamber for observing the effects of inadequate change of air.

sides are arranged a series of six openings each .71 inch in diameter, which may be closed by means of screw-caps; and two air-tight observation windows of glass. In the cover is a ventilation opening over which may be screwed a short ventilating shaft beginning at the cover, or another long enough to withdraw air from near the bottom. Inside the chamber is placed a lighted kerosene lamp with a No. 1 burner carrying a five-eighths inch wick, and turned up until, in an abundant supply of air, it burns kerosene at the rate of 13.783 grams per hour or .109 gallons per day. With this apparatus the following results were obtained:

(1) With this ventilation chamber in the still air of a room, with the cover on but not sealed with oil; with the ventilator closed and with the six windows open, each pro-

vided with a thin muslin screen possessing a pore space through which air may pass equal to 29.36 per cent of the total area, it was found that in two minutes the flame dropped from full height to below the top of the shield of the burner, and went out at the end of 11.5 minutes. Here we have the conditions of a steam or hot water-heated room provided with six open but screened windows, in which the lamp could burn but 11.5 minutes.

(2) With the six windows open but screened; with the ventilating shaft in place, open and drawing air from the floor level, the flame dropped below the top of the shield in 6 minutes and was extinguished in 23.5 minutes. Here we have ample opportunity for air to escape from the room but inadequate entrance capacity.

(3) With the six windows open but screened; with the ventilating shaft in place but drawing air from the ceiling, the flame fell below the top of the shield at the end of 9 and was extinguished at the end of 27 minutes. In this case, with the hottest air at the ceiling and able to enter the ventilating shaft at that level, a stronger draft was produced, compelling a larger supply to enter through the window screens.

(4) With all of the conditions the same as in (3) except that the muslin was removed from one window, in 16 minutes the flame fell below the top of the shield but at the end of two hours was still burning, showing no signs of going out. In this case the hottest air is able to fill the ventilator and with the same difference of pressure but with one window entirely free more air may be drawn in in a unit of time, the amount being barely sufficient to maintain a small flame.

(5) When an 8-inch electric fan was so placed as to throw a strong current of air directly across the top of the ventilator, but with no direct current against the windows, the small flame being maintained under the conditions of (4) was in one minute increased in size to its normal free air dimensions. Here we have five windows screened, one window open, and a strong wind blowing across the top of

the ventilator, the wind increasing the draft until the chamber is sufficiently ventilated to meet the needs of the lamp.

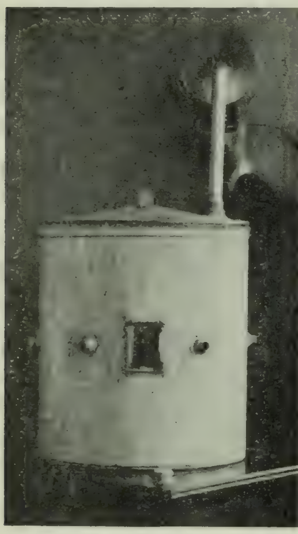


Fig. 15.—Wind across ventilator increases draft.

(6) With the fan still running and unchanged in position with but the ventilator closed the flame in 6 minutes fell below the shield on the burner and at the end of 16 minutes had extinguished itself. With the strong wind blowing over the top of the chamber, with the six windows open and five of them screened, but without an active ventilating shaft, an inadequate supply of air was provided.

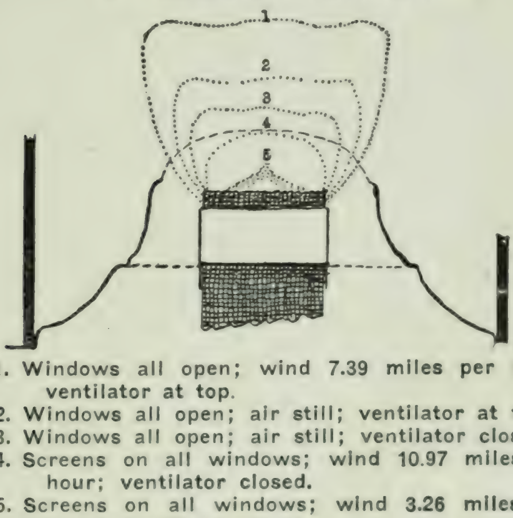
In Fig. 16 are shown the relative dimensions of the flame under the five conditions stated by the corresponding legend.

In these trials the wind blew directly against the windows and sides of the chamber and the air movement was measured with a delicate air meter.

In another demonstration a silver-laced Wyandotte rooster weighing 5.5 pounds was substituted for the lamp in the chamber of Fig. 14. The ventilator and five windows were closed, the other screened with muslin. Under these conditions and surrounded by an air temperature of 60° F. at the end of 5.5 hours the bird was in distress, breathing heavily, gasping with each inspiration. At this stage the six windows were all opened but covered with the screens and 2.5 hours later the bird was still breathing even more heavily and with greater distress. The ventilator in the cover was then opened but covered with a screen. After 10 hours there had been perhaps a little improvement, if so it was very slight. The screens were then all removed from

windows and ventilator and at the end of 2 hours the rooster was standing up apparently comfortable and breathing normally, presumably he was getting air sufficient to meet his needs. It should be observed, however, that in this case special provision is made for both incoming and outgoing currents.

VARIATION IN THE SIZE OF FLAMES UNDER PERFECT AND IMPERFECT VENTILATION



1. Windows all open; wind 7.39 miles per hour; ventilator at top.
2. Windows all open; air still; ventilator at top.
3. Windows all open; air still; ventilator closed.
4. Screens on all windows; wind 10.97 miles per hour; ventilator closed.
5. Screens on all windows; wind 3.26 miles per hour; ventilator closed.

Fig. 16.—Here are represented five sizes of flames, natural size, as they were maintained under the ventilation conditions named in Nos. 1, 2, 3, 4, 5, the burner being that of the lamp and the chamber the same as shown in Fig. 14.

A hen of the same breed weighing 4.5 pounds, placed in the same chamber with all openings closed, became severely distressed for want of ventilation at the end of 4 hours, 13 minutes and died from the effects 4 minutes later. In this case the cover was sealed with oil and corresponds with the trial with the candle in the two-quart Mason jar, Fig. 13, which extinguished itself in 30 seconds, the chamber having 44 times the capacity of the two-quart jar. The candle was

breathing in 115.5 cu. in. of air and died in 30 sec., using 3.85 cu. in. per sec.; the hen was breathing in 5,089 cu. in. and died in 15,420 sec., using but .33 cu. in. per sec.

SERIOUS EFFECTS FOLLOW INSUFFICIENT VENTILATION.

In the demonstrations made with the ventilation chamber referred to in the last section (Figs. 14 and 15) it was made clear that as the ventilation became less and less perfect the size of the flame of the lamp was reduced until in the end it was no longer able to maintain itself. So, too, must it be with the functional activities of the body. The processes and conditions which maintained the flame of the lamp are identical in principle with those which maintain the functional activities of the various organs of the body. The rate of the carrying of oxygen to the flame and that of the bearing away of the products of combustion determined its size and the intensity of the heat and light generated by it, these decreasing from 1 through 2, 3 and 4 to 5 as the air movement through the chamber became less rapid, and so it must be with those functional activities within the animal body which constitute the sum total of its life; these must decrease in intensity or magnitude of activity just in proportion as the life-giving oxygen is borne to, and the waste products are carried away from them.

Blood passing through the active tissues is fully vitalized only when it is doubly charged, first, with the oxygen from the air breathed and, second, with the other nutrients eaten and drank. Neither can be efficient except as the other is present, ample and effective. The lamp, under the conditions of 5 had an abundance of oil, the wick was full, the temperature right but the oxygen was deficient. There could be no larger product in the form of flame except as the oxygen supply was made continuously larger. The conditions for activity in the body tissues are no less rigid; they are of the same type. It requires more oats and more hay to maintain day after day a team turning two 18-inch furrows than it does another turning two of 12, and pro-

portionately more air must be taken in. If you increase the daily ration of grain and hay with a view of doubling the output of milk there is no other possibility for the herd than for it to charge its blood with enough more oxygen to make the extra product. If the herd is in the free air of a pasture it will do this easily, automatically and with certainty, but if it is in a stable and that stable has a wholly inadequate air movement through it; if the quality of the air in it is to that of the pasture as is the air in the ventilation chamber (Fig. 16) under the conditions of 3, 4 or 5 to those of 1, then the herd will be helpless to help you and a menace to those who use its product.

The extremely serious aspect of inadequate ventilation results not so much from its effects in diminishing functional activities and in depressing the vital powers in their ability to do useful work as in its tendency to derange the order of chemical processes in the body leading to the formation and accumulation of products in the tissues which render the individual whose functions are so disturbed peculiarly liable to disease and especially to those of zymotic or contagious types, such as cholera, smallpox, diphtheria and tuberculosis. This world is marvelously full of germs of unnumbered kinds and possibilities. Let a fire sweep away any forest, no matter how dense or how many centuries old, with the first rain and genial sun there springs out from the ashes, upon almost every square inch of surface laid bare, some plant from seeds, perhaps of a hundred kinds, wafted thither by the winds, floated on the waters, brought by the birds or dropped by former occupants of the soil; seeds which have laid dormant perhaps many years or which have been resown a thousand times, waiting the moment when the forest should lose its mastery over the soil. Nature has neither empty places, idle moments nor neglected opportunities where the conditions for life exist. Everywhere out of the weak, out of the dying and out of the dead, as well as out of the soil and out of water, life is springing. Eternally is somebody waiting for everybody's shoes, for all life is a competitive struggle,

continuous, intense, and hence inadequate ventilation or anything which interferes with the normal action of the body, causing weakness, becomes an entering wedge, opening out an opportunity for the attack of some disease producing germ.

Plant any seed in a too cold, over-wet, insufficiently ventilated soil and it at once absorbs water, its stored food materials dissolve and, unless the other conditions favorable for germination are present, this soluble plant food will be at once appropriated by the many micro-organisms existing in the soil and which are better able to thrive under the conditions surrounding the seed. The result is the seed is robbed of its stored food, its vitality becomes thereby lowered and either its life is destroyed or it reaches maturity giving a reduced yield. Likewise we should never forget that in the case of our own bodies and in those of our domestic animals there is continually a struggle for mastery between the normal living cells which constitute the various organs and many lower life forms always present in the system as the seed are in the forest soil, simply biding their opportunity. Any condition, therefore, like that of an insufficient supply of pure air, insufficient or improper food of other kinds, which must tend to lower the vitality or intensity of action in the cells of any organ is likely to place them at the mercy of the invading germs which, like weeds in the field, are simply biding their time to spring into overmastering supremacy, thus bringing disease and perhaps death as the result.

We fully appreciate that in a highly fertile soil, well managed, crops are less liable to disease and that they much more readily keep the mastery over weeds than they do on a poor soil or on one in bad condition, poorly managed. It it equally true with the organs of the animal body; if they are abundantly nourished, surrounded by congenial conditions, the possibilities for contracting tuberculosis, cholera, smallpox or other forms of contagious diseases whose germs we must remember are almost always about us, no matter how careful we may be, are very much reduced. It is the

body starving for want of oxygen or for want of any other essential food material, or which is weakened in any other way, which is most likely to be overpowered by one or another of these foreign organisms, and a single germ may gain the mastery over a system in weakened condition where multitudes of them would be harmless within a vigorous constitution, well nourished and normally cared for. And since the body out of which life has gone begins immediately to pass into decay it stands to reason that one sick or weak must be more liable to suffer from attack than another who is strong, and the truth of this is abundantly borne out by statistics, particularly by those expressing the rate of mortality resulting from contagious disease associated with conditions of inadequate ventilation.

Fig. 17.—Lamp burning with full supply of air, without smoke.

As a concrete illustration of the manner in which insufficient air may alter the nature of chemical changes let this lamp, Fig. 17, be used, which is burning with a full bright flame under the influence of a strong current of air. The moment this current is cut down by holding the hand under the draft, Fig. 18, the chimney fills with a sooty flame and smoke. There is not enough oxygen carried by the reduced current to unite with both the hydrogen and the carbon of the kerosene and, as the hydrogen has a stronger attraction than the carbon for oxygen, it appropriates so nearly the whole that a portion of the carbon is set free in the form of smoke. There is thus formed a waste product abnormal to the lamp in healthful operation and if allowed to continue would ultimately clog the chim-

Fig. 18.—Lamp burning with insufficient supply of air resulting in smoky flame.

ney through deposits on the wall, thus extinguishing the flame by entirely shutting off the air supply. Insufficient ventilation may in like manner result in abnormal chemical processes in the body, giving rise to products which if allowed to accumulate in the system become positively injurious. It is of course not intended to convey the impression that if respiration is compelled to go on in an insufficient supply of oxygen carbon will be deposited in the tissues, as soot was deposited on the chimney, but there are good reasons for thinking, indeed direct observations show, that when there is an insufficient supply of oxygen in the air breathed, as when the carbonic acid content is abnormally high, materially less carbon dioxide is thrown off. In the experiments with the fowls cited there accumulated in the ventilation chamber a very large amount of moisture, enough not only to wet the walls so that it ran down the sides but to so saturate a layer of dry sand which was used as an absorbent as to cause the surface to appear wet.

In April, 1891, we conducted, during 14 days, an experimental study of the effect of ample and deficient ventilation upon 20 milch cows. The experiment was made in a half-basement stable, represented in Fig. 19, having three outside doors, thirteen large windows and a door leading by a stairway to the floor above. The ceiling was nine feet above the floor and the stable contained 960 cubic feet of space per cow. Leading upward from the ceiling there were two hay chutes 2 by 3 feet in cross section, 20 feet high, which could be opened or closed at will, and a ventilating flue, 12 by 16 inches, terminating near the ridge of the roof inside. The experiment consisted in closing all doors and windows and the two hay chutes, leaving only the ventilating shaft open, for the trials under insufficient ventilation; and in leaving both hay chutes open, together with the ventilating flue, for good ventilation.

During the trial the cows were kept continuously in the stable, with the hay chutes closed during two days and then with them open two days, the trials being repeated four

times. Following these four trials the hay chutes were closed during three consecutive days for poor ventilation and left open the following three, making 14 days in all. The feed eaten, the water drank, the milk produced and the

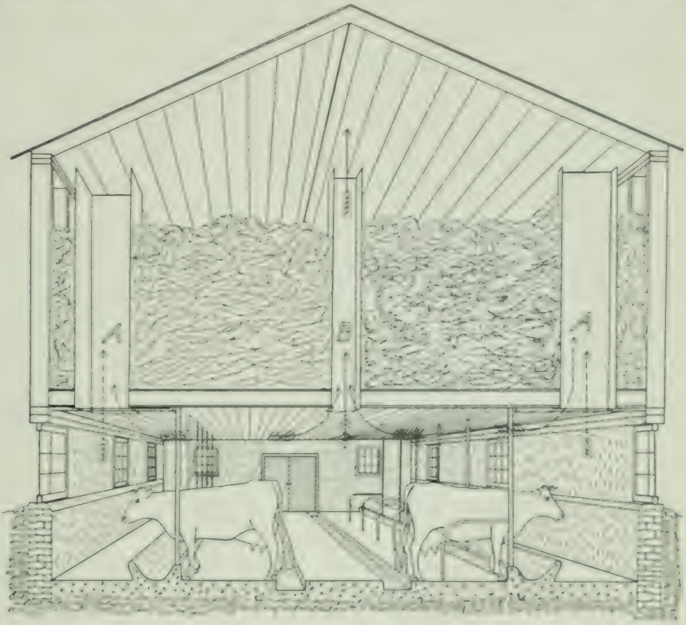


Fig. 19.—Stable in which ventilation experiment was conducted. One or more hay chutes, with no ventilating flue, has been a common way of ventilating dairy stables; often the chutes are absent.

cows themselves were weighed each day. It was found that measurably the same amount of feed was eaten under both conditions of ventilation. But during the days of insufficient ventilation the cows drank, on the average, 11.4 pounds more water each daily and yet lost in weight an average of 10.7 pounds at the end of each period, regaining this when good ventilation was restored, and this too when they were drinking less water. During the good ventilation days too, for each and every period, the cows gave more milk, the average being .55 pounds per head per day.

At the end of the 14 days the cows were turned into the yard and exhibited an intense desire to scratch and lick their sides and limbs, doing so until the hair in many cases was stained with blood. Examination showed that during the interval a rash had developed which could be felt by the hand in the form of hard raised points and the rasping of these off caused the bleeding. In the case of these cows it seems clear that on the days of insufficient ventilation conditions existed which may fairly be compared with those causing the smoking in the lamp; the reduced supply of air in the stable made it impossible for entirely normal chemical changes to take place in the body; it was impossible for the lungs to remove the waste products in the form of carbon dioxide to as great an extent as was usual and it seems highly probable that because of this some of the waste products had to be of a different chemical nature, such as could be eliminated through other channels. But if this was true a stronger action on the part of the kidneys and perhaps on the part of the alimentary canal as well, which created the increased demand for more water to the extent of 11.4 pounds daily, all of which was lost and enough additional to reduce the average weight 10.7 pounds by the close of each period, would seem to justify the conclusion, not only that abnormal chemical changes were taking place in the bodies of the animals, but also that the elimination of impurities so produced was not occurring in the usual way. During the days of insufficient ventilation moisture condensed to such an extent on the walls and ceiling as to drip and run down the sides; at the same time the odor was very strong and the air depressing to one coming in from outside.

It is important to point out here that the appointments of the stable in which these trials were conducted are typical of perhaps a majority of dairy stables in the United States today; furthermore, it is a very common practice to close hay chutes and similar openings during cold weather, especially during the night, thus establishing the precise conditions designated in this experiment as poor ventila-

tion and which produced the observed results. The dampness in the stable due to condensation of moisture, the offensive odors and the oppressive character of the air which have been referred to as occurring in the experiment described are all present in the average dairy stable in greater or less intensity wherever ample provision is not definitely made to secure proper ventilation.

VOLUME OF AIR WHICH SHOULD MOVE CONTINUOUSLY THROUHG DWELLINGS AND STABLES.

"Jane, you and Ellen go up and do the chamber work and be sure to open the windows and give the rooms a good airing." Yes, indeed, but why not a better airing during all the night when the sleepers are occupying the beds. Certainly a refreshing drink direct from the spring, and a full supper from the dining room, easily satisfy all cravings from an early to bed to a late to rise. And will not a full breath or at least a half hour of them, when drawn from the park or from the pasture, as fully meet the needs of a night? Perhaps Mother's caution does imply this or was it her remembrance of a weary waking from an unrefreshing sleep; a mother's feeling that something surely ought to be done and she would faithfully do the little that lay in her power? Or is the idea really prevalent that to have the chamber full of outdoor air to start with will generally meet the requirements of the night?

It is difficult for many, and perhaps for most people, to harmonize their own experience in this matter of ventilation with those who advocate the imperative need of special provision to secure ventilation, as it seems clear that since no such provisions are generally made for either dwellings or stables and since no serious consequences have certainly resulted which are ascribed to the lack of such provisions they can hardly be regarded as necessary. For all such let them be urged to reflect that the animal mechanism possesses a marvelous power of endurance and for the tolerance of conditions even seriously injurious and that usually the

existence of such pending troubles are not recognized until it is too late and that even when they are recognized their true cause may remain unknown. Above all should it be emphasized and ever borne in mind that there is an extremely wide range in the powers of endurance of foul air, not only among different animals, but among individuals of the same species, so that wherever more than one is occupying a compartment the degree of air purity must certainly be such as to meet the needs of the least tolerant occupant. Not only does the lung capacity of individuals vary but the depth of respiration is very different owing to difference in habit or difference in dress, thus making it impossible for all to derive the same amount of oxygen, or eliminate the same amount of carbon dioxide under like conditions of air. Such differences are of course exaggerated in all cases where the lung capacity is reduced on account of disease.

When the breath is forced into a cold lamp chimney or glass vessel there is at once perceptible a marked condensation of moisture on the walls, showing that very material quantities of moisture are being discharged in invisible form into the air. So too, if the hand is placed for a second with the palm against the cold surface of a mirror and removed before the surface has been warmed there will be apparent in this case also a marked condensation of moisture, showing that not only from the lungs but from the skin as well the air of compartments is being continually charged with moisture. In the case of man the mean amount of moisture exhaled from the lungs and transpired by the skin is placed by Seguin at 1,080 grains per hour, the minimum being 486 and the maximum, except under very unusual conditions, 1,458 grains per hour. This moisture discharged into the air of a compartment in which no change is taking place tends rapidly to saturate it, soon bringing it to a point where moisture condenses on the walls. If we would not have this moisture condensation there must necessarily be a movement of air through the

room sufficient in volume to carry away the moisture as rapidly as it is formed.

The ability of air to carry moisture under given conditions of temperature and pressure is very definitely known; hence it becomes possible to compute the volume of air which must pass through any compartment where a known amount of moisture is being thrown into the air, in order that this moisture may be carried away as rapidly as formed. The following table has been computed from Seguin's data, using the Smithsonian table 167 giving the capacity of air for moisture.

Volume of air 75 per cent saturated at 40°, 50°, 60°, and 70° F. required when leaving the room saturated at 70°, to remove the minimum, average and maximum amount of moisture thrown off from the lungs and skin per hour, by man.

	When the temperature of the incoming air is, 40°	50°	60°	70°
	The required hourly movement of air is,			
	cu. ft.	cu. ft.	cu. ft.	cu. ft.
Minimum..........	83	99	132	244
Average...........	185	220	294	541
Maximum..........	250	296	397	731

From this table it is seen that in order to remove from a compartment the moisture thrown into its air as invisible vapor from the lungs and skin, so as to avoid oversaturation, there must be moved through it each hour more than 185 cubic feet, 220, 294 or 541 cubic feet on the average for each occupant, according as the air enters at 40°, 50°, 60° or 70° F., the air at the same time passing out fully saturated at 70°. It is clear, therefore, in order that dwellings and especially schoolhouses, churches and stables may have a reasonably dry atmosphere there must be a large and continuous air movement through them which is proportioned to the number of occupants.

From the recent studies of Dr. Armsby it was determined that a 1,000-pound steer charges the air of the stable with

invisible vapor, from skin and lungs, to the extent of no less than 10.4 pounds daily. In order, therefore, that a dairy stable of twenty cows may not have the moisture condensed on its walls there must be an air movement through it continuously sufficient to remove 208 pounds daily; for 40 cows it must be sufficient to remove 416 pounds; for 60, 624 pounds; for 80, 832 pounds and for 100 cows there must be a movement which will carry from the stable through the out-going air, as invisible vapor, 1,040 pounds, or more than half a ton, of moisture daily. The mean amount of moisture carried by the air in most parts of the United States at 7 A. M. is seldom less than 70 per cent of its full saturation capacity. In the next table there are given the volumes of air per hour and per cow which must pass through a stable in order to prevent condensation.

Required number of cubic feet of air, per hour and per head, to prevent condensation of moisture when it enters the stable 75 per cent. saturated and leaves it saturated at the stable temperature.

If the outside air is 75 per cent saturated at the temp. of	When the stable temperature is, 30°	40°	50°	60°	70°
	The volume of air per head and per hour must be,				
	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
−10° F	1,788	1,164	792	540	394
0°	1,982	1,253	832	554	402
10°	2,334	1,385	887	569	415
15°	2,620	1,489	931	614	424
20°	3,140	1,634	996	638	434
30°	6,228	2,201	1,165	715	466
40°	....	4,268	1,566	842	520
50°	....	....	1,782	1,126	655

This table makes it clear that in dairy stables a large and continuous movement of air through them is imperative simply to prevent the condensation on the walls of the moisture of perspiration and respiration; and the dampness so often observed in basement stables is a proof positive of the too slow rate of change of air in them to even carry out the moisture. When the outside air containing three-fourths of all the moisture it can retain at a temperature of 0° enters a stable which is maintained at 70° F., then 402 cubic feet per cow must enter and leave the

stable each hour to completely remove all the moisture thrown off by the skin and lungs. If the stable temperature is maintained at 60° instead of at 70° then the air movement must be at the rate of 554 cubic feet; if at 50°, 832 cubic feet; if at 40°, 1,253 cubic feet, and if the stable temperature is as low as 30° then, with the air entering the stable three-fourths saturated at 0°, no less than 1,982 cubic feet of air must enter and leave the stable for each cow each hour. And so if the outside air is three-fourths saturated at 20° and the stable temperature is maintained at 70°, the necessary air movement, to keep the stable dry, is 434 cubic feet per hour and per cow; but if the stable temperature is 60° then the amount must be 638 cubic feet; if 50°, then 996 cubic feet; if 40°, then 1,634 cubic feet; while if the stable is as cold as 30° then the air change must be at a rate exceeding 3,140 cubic feet per hour and per cow to carry away the moisture thrown off. These last statements mean that when 20 cows are housed in a stable with a floor space 20 by 40 feet and with 9 foot ceiling this entire volume of air must be changed once every 50 minutes when the stable temperature is 70°; once every 33 minutes when the temperature is at 60° once every 21 minutes if it is at 50° once every 13 minutes if it is at 40° and if the stable temperature is as low as 30° then the entire volume of air in the stable must be changed as often as every 7 minutes in order to prevent moisture condensation. It is thus seen that the lower the temperature of the stable and the higher the temperature of the outside air before entering the stable the larger must be the air movement through it in order to carry away all the moisture exhaled by the animals.

But large as must be the air movement through stables simply to keep them dry this is not sufficient to maintain the required purity of air to meet the needs of the animals themselves either in the oxygen supply or in the removal of carbon dioxide and the poisonous volatile organic products exhaled by them. It must be held of the highest importance, from the standpoint of house and stable sanitation,

that some standard of air purity should be experimentally determined so that the rate of air supply for each individual, which constitutes adequate ventilation, shall be definitely known and shall be used in house and stable construction in making definite provision for adequate ventilation.

De Chaumont has assumed a standard of purity of air for man of 99.51 per cent, which means that the carbon dioxide in the air of a room due to respiration should not be augmented more than two parts in ten thousand over that carried by pure air, or more than .02 volume per cent. This limit, too, is found by direct observation to be that at which the sense of smell fails to detect the odor of "closeness" in an occupied room. Carnelly, Haldane and Anderson admit a standard of purity much lower than this and it is commonly held that, for man, when the air of a room contains no more than .07 volume per cent of carbon dioxide it is sufficiently pure for the purposes of respiration. In using the carbon dioxide as a standard it is held by writers on ventilation, not that more or less of this would be injurious, but rather that this amount of carbon dioxide is an index of the degree at which the "crowd poisons" have become sufficiently concentrated to be injurious. We feel that it may quite as likely express the degree of oxygen-exhaustion at which the more sensitive occupants of a room begin to feel the depressing effect of an insufficient supply of oxygen in the system, and the time at which deeper breathing needful to compensate for exhaustion becomes a conscious effort. De Chaumont's standard of purity requires an air movement of one cubic foot per second for each adult man when at rest, or 3,600 cubic feet per hour. Men in active labor would require more, while women and children at rest would need somewhat less. The other standard of purity would require an air movement of about 1,800 cubic feet per hour for an adult man at rest and would hold the composition of the air of the room at 99 parts pure and one part at the degree of exhaustion of once-respired air, and in this condition its oxygen content would be reduced

from 20.582 volume per cent, as stated in the table for moist air, page 13, to 20.529 per cent, an exhaustion of its oxygen content amounting to .05 volume per cent of the air and of .26 per cent of the oxygen itself. De Chaumont's standard of purity would permit exhaustion to but one half of these amounts.

In dealing in a practical way with problems of ventilation, providing means for the entrance into and exit of air from dwellings and stables, it is necessary to take into account the openness of structure which is unavoidable under present methods and materials of construction, for the reason that in consequence of this openness of structure there results a not inconsiderable air movement into and out of compartments through openings not intentionally provided, and which does much toward providing the necessary air supply, even when the wind movement outside is small. That material changes of air do take place through the walls of buildings we have abundant proof, and experiments conducted at the Geneva Experiment Station, N. Y. furnish a basis for computing what this rate of movement was under one set of conditions. The stable in question had a floor space of 51 by 33 feet with a 9 foot ceiling, accommodating at the time 22 cows. Doctor Jordan was having a study made of the distribution of carbon dioxide in the stable air and during one set of observations, when the ventilators were open, the mean content of carbon dioxide was found to be .462 volume per cent, .534 per cent near the ceiling, .501 at a middle level and .351 near the floor. If we may take the composition of once-respired air in this case at the value given in the second part of the table, page 14, and the amount of air breathed per hour and per cow at 116.8 cubic feet, page 9, the degree of purity of air in this stable must have been at the time 89.72 per cent and air must have been entering and leaving it at the rate of some 24,995 cubic feet per hour, or 1,136 cubic feet per cow. When the ventilators of this stable were closed, however, the carbon dioxide present in the air had increased so as to be 1.40 volume per cent near the ceiling, 1.236 per cent at

a middle level and 1.034 per cent near the floor, making an average of 1.2233 volume per cent. On the same basis of calculation as used above air in this case must have been entering and leaving the stable at a rate of some 9,059 cubic feet per hour, which is nearly 412 cubic feet per cow, and the air in the stable at this time had a degree of purity approximating 71.63 per cent, which means a reduction of the oxygen content to 19.13 volume per cent, a lowering below that of standard air of 1.36 per cent. We have, therefore, in this case, a dairy stable accommodating 22 cows, built close for warmth and having all its special provisions for ventilation closed, yet with air entering and leaving it at the rate of more than 9,000 cubic feet per hour, the air being changed in the stable as often as once in every 100 minutes, whereas, when both the intentional and unintententional facilities for interchange of air were in operation the air of the stable was changed once in about every 36 minutes.

At the Minnesota Experiment Station experiments were conducted which furnish another basis for making a similar estimate regarding the permeability of stable walls to air. In this case a steer was kept during varying intervals of time in a closed stall having a capacity of 784 cubic feet with one outside wall and a single window. The stall was provided with a cement concrete floor, the walls were of hard brick and the ceiling of boards, which was covered with heavy muslin, this and the walls being painted to render them more nearly air tight. The window and a door opening into a hallway were close fitting and the door was so arranged as to permit the animal to be fed and watered without opening the door, the animal being cared for without the attendant entering the stall except at the close of an experiment. Under these conditions there was a wide variation in the composition of the air in the stall, the data showing a range between .52 and 2.67 volume per cent. of CO_2. The authors say "After the work had been in progress for a short time the windows, walls and ceiling became covered with water which at times ran down the walls and

dripped from the ceiling. The quantity varied with the condition of the weather. After the stall had been closed several days at the beginning of Series B mould began to appear on the walls and gradually increased until almost the entire wall surface was covered. After the closed stall was in use several weeks it was noticed that the paint was softened in several places on the wall and running down with the water. This continued until almost the entire wall surface was bare of paint."

"After entering the closed stall at the close of a period to make a reading or remove an animal one was forcibly impressed by a stifling air, its excessive moisture and the apparently high temperature. The first few minutes one invariably had difficulty in breathing, this soon passed away, and he began to sweat, and feel uncomfortably warm. This condition did not last long, perhaps five minutes, after which no unpleasant effects were noticed. After leaving the stall the outside air seemed cold and so light that one involuntarily took several very deep inspirations. The odor of manure did not become sufficiently strong to be offensive even at the close of a 10-day period."

We have here what would appear to be extreme conditions as to closeness of construction; conditions under which steers were kept and fed continuously without leaving the stable and without having the door opened, except the slide through which feed was quickly introduced, for periods, in one case, as long as 28 days; conditions in which the experimenter thought the animals did not seriously suffer from the effects of insufficient ventilation; but conditions which the experimenter himself invariably found oppressive, as he has described above, on entering the stall at the close of an experiment. It seems quite clear from the analyses of the stable air which were made that there must have been a very considerable air movement through the stable at all times whenever there was a considerable wind movement outside. Taking the average weight of the animals experimented with at 600 pounds and assuming a respiration volume proportional to this weight and, further, that the

consumption of oxygen and excretion of carbon dioxide occurred in the normal ratio, we may calculate the air movement through this stall by the same method used in the case of the dairy stable. When such a calculation is made a .52 volume per cent of carbon dioxide maintained in the stall air requires a continuous flow at the rate of some 591 cubic feet per hour, and when the content of carbon dioxide was maintained at 2.67 per cent an exchange of air is required at a rate not less than about 112 cubic feet per hour. It must not be understood that the values here computed, relating either to this stall or to the dairy barn which has been considered, have more than an approximate degree of accuracy. They undoubtedly do express a general and important truth, namely, that material volumes of air do enter and leave what are regarded as closely constructed dwellings and stables by means of openings not specially provided, and that the amount of such movement varies between extremely wide limits, as must have been the case in the Minnesota stall, the ventilation being best when the wind movement is greatest outside. It is clear however, from the data presented in this connection, that even under the best of outside conditions close stable and dwelling construction can seldom give adequate ventilation, certainly never at times when the air is still.

The experiments conducted at the Minnesota Experiment Station lead the authors to say: "Cattle seem to thrive under what are apparently the worst possible conditions of stabling. Beef cattle fatten well and dairy records are made in stables that are simply abominable from recognized standards of good stabling. * * *

"Stable ventilation in our northern states during our long cold winters is a difficult problem at best. To get anything like the amount demanded by most authorities is certainly impracticable. If less is compatible with the health and comfort of our confined stock it is very important that we know it and be quite sure of it. If what we call moderately or even decidedly foul stable air is not commonly inimical to the health and comfort of these animals or to the

owner's profits then it is of the utmost importance that we know this also. * * *

"The real problem with which we have to finally deal is, how little air is compatible with normal health and comfort of the stock and with economic feeding."

It is very unfortunate that language like this should find a place in the instructional literature of animal husbandry for it is certainly much nearer the truth and conducive to a safer practice to say: *The real problem with which we have finally to deal is how nearly can we maintain the air of dwellings and stables at the normal out-of-door fresh air purity with practicable economy.* It has certainly never been a maxim of good feeders to supply the smallest ration "compatible with the normal health and comfort of the stock and with economic feeding." Rather has it been the practice to place before the animals the largest amount of feed they can possibly be urged to eat and return a good profit. A like maxim must lead in the supply of air which constitutes more than two-thirds of every adequate ration.

In our study of stable conditions and of the possibilities of air supply we have been led to the conviction that an air movement through the stable can and should be secured which will maintain a degree of purity not lower than 96.7 per cent; that the air of stables and dwellings should at no time contain more than 3.3 per cent of air once breathed. Such an air movement as this is entirely practicable in the stables of cold climates and a much higher rate is possible in every properly heated dwelling.

In order that the air of a stable shall at no time contain more than 3.3 per cent of air once breathed it must enter and leave at the rate of 4,296 cubic feet per hour and per head for horses, at the rate of 3,542 cubic feet for cows, of 1,392 cubic feet for swine, of 917 cubic feet for sheep and of 35 cubic feet per hour for hens, on the average. In the case of man the amount of air breathed per hour is 17.71 cubic feet and the hourly movement through the dwelling and sleeping room, in order to maintain the degree of purity stated, needs to be not less than 537 cubic feet for each adult.

These several amounts are graphically represented in Figs. 20 and 21.

To secure an air movement through a cow stable containing 20 cows a ventilating flue 2 feet by 2 feet is required through which the air moves at the rate of 295 feet per minute. A flue of this size, too, will be required for 17

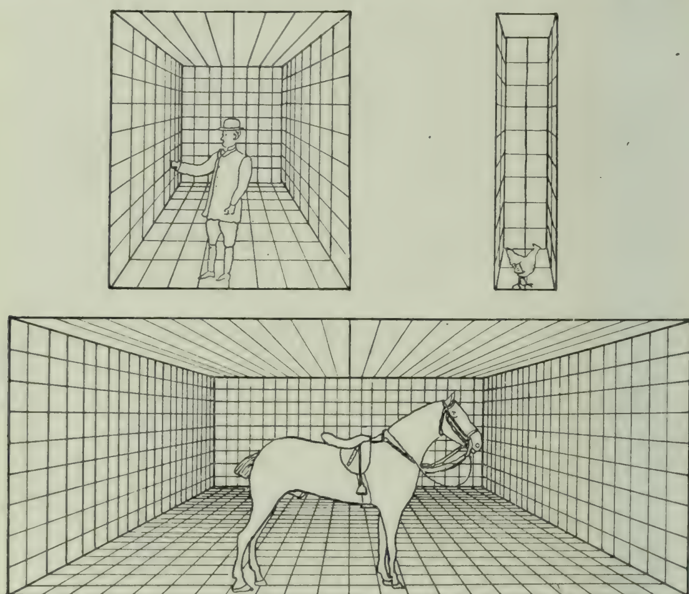


Fig. 20.—Each drawing represents the volume of air which should enter and leave the stable or room during each hour for each adult occupant. Each square represents a square foot and the subdivisions indicate the number of cubic feet in each room.

horses, for 51 pigs and for 77 sheep. Double the number of animals named will require ventilating flues having nearly double the cross section stated while smaller numbers would require flues relatively larger in proportion on account of the relatively greater friction in small, as compared with that in large flues.

To emphasize, we wish again to state that *it is a matter of the highest economic and sanitary importance that rigid*

experiments should be instituted, both for man and for domestic animals, which shall establish beyond all doubt what is an entirely sufficient degree of air purity for dwellings and for stables to the end that a safe basis may be had upon which to specifically provide proper and fully adequate means for ventilation. It is important to recognize that the

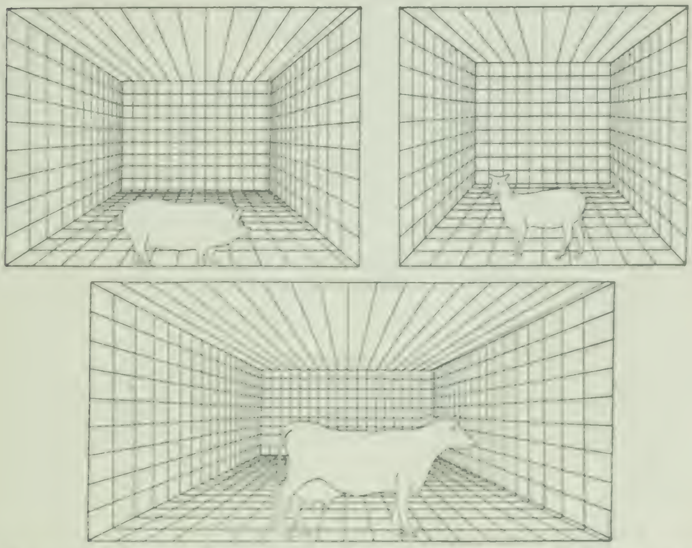


Fig. 21. Each drawing represents the volume of air which should enter and leave the stable during each hour for each adult occupant. The rulings indicate the number of cubic feet in each room, each square is one foot.

standard of air purity here assumed is materially below that which admits a content of carbon dioxide in the air of a room of .07 volume per cent. Indeed the standard assumed for stables permits a content of carbon dioxide as high as .167 volume per cent, a quantity more than double that above; and it is important to say again here, for comparison, that Doctor Jordan found in his stable, with the ventilation system in operation, a carbon dioxide content as high as .462 volume per cent, which is nearly three times that of the standard we have assumed for stables. In his

case the degree of air purity was 89.67 volume per cent instead of 96.7 which we have assumed as a probably safe limit. Should it be found admissible to tolerate in a stable 5 to 10 per cent of air once breathed, instead of 3.3 per cent, which is here assumed, such a degree of purity could be more readily secured under all conditions of weather. We feel that it would be unwise, however, to adopt a lower standard, in advance of definite knowledge, in stable construction for the reason that it is a very simple matter to reduce the air movement through a stable when the large capacity of the ventilating system causes the rate of change to be too high. If the capacity of the system is too small there is no help except that of resorting to open windows or similar devices which are undesirable in cold weather, particularly if it is windy.

PRINCIPLES OF VENTILATION.

The installation of a satisfactory system of ventilation requires (1) The choice of a proper unit of air movement; (2) the application of the laws and principles governing air movement; (3) and the adoption of proper construction with adequate motive power to insure the required supply of air. There can be no proper ventilation for dwelling or stable unless into it and out of it there is a continuous flow of air at some proper unit rate. It has been pointed out that some have adopted as this proper unit for man a cubic foot of air per second; that others have accepted one half this volume as adequate; and that we have taken as possibly sufficient for the cow 3,542 cubic feet per hour. Without contending that either of these units is the best it must be insisted that *some unit should be chosen* and then adequate provision made to secure at least this amount. It should be recognized, too, that in increasing the air movement beyond the standard chosen there is little chance that injurious physiological effects will follow as the result of such choice provided a proper temperature is at the same time maintained.

Unnecessary expense of installation and maintenance is about the only chance for mistake against which to guard; and in the matter of expense it should be remembered that where the forces which maintain the air movement through the ventilated space are the wind and the waste heat of occupants or of heating and lighting appliances the cost of a ventilating system above the standard capacity will be only that required to incorporate a somewhat larger amount of material in its construction. It is the part of wisdom, therefore, to install a ventilating system whose capacity shall be abundantly large.

The maintenance of a flow of air through a building requires the continuous expenditure of energy and the amount of this energy and of work done will be in direct proportion to the weight of air moved through the ventilated space and the resistance it is necessary to overcome in accomplishing this movement. If the air of an audience room occupied by 1,000 persons is supplied at the rate of 537 cubic feet per hour and per capita the work to be done is approximately that of moving some 21[1] tons of air through the room each hour.

If De Chaumont's standard of one cubic foot of air per second and per person is adopted then the amount of work to be done is that needed to move through the room 144[2] tons of air.

So, too, if a herd of 100 dairy cows is to be supplied with air at the rate of 3,542 cubic feet per head and per hour the necessary amount of work is that of moving through the stable each hour 14 tons,[3] which, if the air is forced through vertical shafts 40 feet in length, of ample capacity, represents about one-half horse power.

POWER USED IN VENTILATION.

The motive power commonly utilized in ventilation is (1) the passing wind; (2) heat generated within the space to be ventilated by its occupants, by lights and by fires; (3) rotary fans driven by one or another source of power; (4) and steam jets or coils in ventilation flues. By whatever source of power the air movement for the purposes of ventilation is effected this results from a difference of pressure established between the air in the space to be ventilated and that outside, and this difference of pressure is the immedi-

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[1] $\frac{537 \times 1000 \times .08}{2000} = 21.48$ tons.

[2] $\frac{3600 \times 1000 \times .08}{2000} = 144$ tons.

[3] $\frac{3542 \times 100 \times .08}{2000} = 14.168$ tons.

ate cause of air movement into and out of the ventilated space.

When the wind has its progress arrested or checked by a building pressure is developed; this pressure tends to force air through any pores, chinks or openings which may exist in the wall. But if air is forced into the building that inside will be placed under a greater pressure and this greater pressure will force a flow outward on the leeward side or upward through any chimney or ventilating shaft which may exist. All are familiar with the existence of a much stronger current passing around the corner of a building on a windy day than is found at a distance beyond. This higher wind velocity is proof of the increased pressure which has resulted from the check to its onward progress it has received from the building and this must assist in the ventilation of all buildings whose walls are not absolutely air tight.

The pressure of the wind on a building, and therefore the "head" which tends to force air into it, when the impact is at a right angle, has been found to be approximately given by the two equations

$$\text{Pressure or Head} = .005\ V^2 \text{ or}$$
$$\text{Pressure or Head} = .00096\ V^2$$

where V is the velocity of the wind in miles per hour, the result being in pounds per square foot of surface in the first equation, and in inches of water in the second. These equations mean that if a wind is blowing at the rate of five miles per hour against the walls of a dwelling or stable, striking them at a right angle, the pressure so developed tends to force air through any openings in the windward side with an intensity approximately equal to .125[1] lb. per sq. ft. and equal to .024[2] inch of water, the precise value varying with the weight of a cubic foot of air at the time, this changing with the temperature, pressure and composition. This amount of pressure is theoretically capable of causing a flow through a smooth,

[1] $.005 \times 5 \times 5 = .125$ lbs. per sq. ft.

[2] $.00096 \times 5 \times 5 = .024$ inch water pressure.

straight cylindrical ventilating shaft or chimney one square foot in cross-section and 40 feet high, equal to some 36,000 cubic feet per hour.

Then too, whenever the wind blows directly across the top of a chimney, ventilator or other opening it tends to produce a suction which has the effect of reducing the pressure at the opening and of causing a flow outward increasing with the reduction of pressure. The magnitude of such wind action, in its tendency to produce a flow of air into and out of spaces needing ventilation, is given by the equation,

$$\text{Pressure or Head} = .00024V^2,$$

where V is the velocity of the wind in feet per second and where the head or pressure is in inches of water. If the velocity of the air is taken in miles per hour this equation becomes

$$\text{Pressure or Head} = .000518V^2.$$

These equations mean that if the wind is blowing at the rate of five miles per hour across the top of a ventilating flue or chimney there would be developed a suctional effect or head equal to, using the second equation,

$$.000518 \times 5 \times 5 = .01295 \text{ inch water pressure,}$$

and this is capable of producing, in a flue 40 feet high with a cross-section of one square foot, a theoretical flow of some 26,000 cubic feet per hour. Such theoretical velocities as these cannot be realized in practice because the resistances met with by the air in entering buildings, ventilating shafts or chimneys vary between wide limits; moreover if provision is made for air to enter through thin openings in walls, such openings are never fully effective because of the interference of currents entering obliquely around the margins, causing a contraction of the air stream which may reduce the theoretical flow to about 65 per cent. The manner in which the wind becomes a motive power in ventilation is indicated in Fig. 22.

The wind has its progress arrested by the building, thereby compressing the air and forcing a portion of it into the building through any openings, as at A, while other

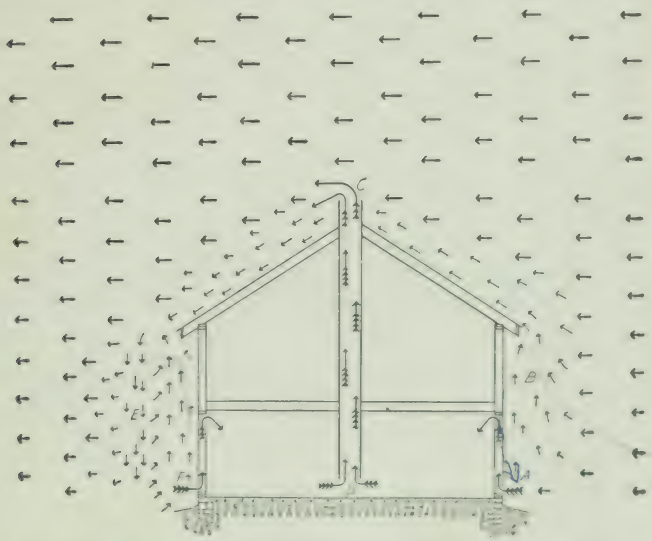

Fig. 22.—Manner in which the wind becomes effective as a motive power in the draft of chimneys and in ventilation.

portions are driven upward along the sides past B and over the roof across the top of the ventilator at C, and other portions still flow around the corners. The air entering the building at A is either forced upward through the ventilating flue at D or out through any openings which may be in the leeward walls of the room. That portion forced past B along the roof, across the top of the ventilator, joins with the general wind current of that level and tends to drive the out-coming air from the flue forward, diminishing the pressure of the air downward into the flue, thus making less resistance for the air in the room below to be overcome in its ascent. The air flowing over the roof of the building increases the pressure on the leeward side at E, out from which air flows on both sides, that flowing toward the build-

ing rising along the sides or entering it at F, as indicated by the small arrows. Thus two sources of power are brought into operation, compelling air to enter the room at A and F and leave it at D, one being the direct wind pressure exerted at A and F and the other the suctional effect developed at C. The flow through the building, resulting from wind pressure and wind suction, will be most rapid

Fig. 23. Showing improper installation of ventilating flues just above the eaves. In such cases whenever the wind is from the opposite direction the tendency will be to give a much reduced draft or even reverse its direction, causing it to be downward into the stable.

when these two factors can be made to act in the same direction and with the highest efficiency. This will be the case when the wind is permitted to reach the building at A and to pass over its roof at C, meeting with the least obstructions. The table, page 57, indicates that the flow due to direct pressure is stronger than that due to suction under like wind velocities. It will generally be true, however, that the suctional effect of the wind is the stronger of the two for the reason that the wind velocity at the top of the ventilating flue will nearly always be materially stronger than near the ground. The fact of wind velocity increasing with

hight above the ground is expressed in Fig. 22 by the length of the arrows, these being aprpoximately proportional to the wind velocities at such levels.

It will be clear from what has been said that the top of a chimney or a ventilating flue should rise well above the ridge of the roof, where the wind has a clear sweep, and not end just above the eaves as is the case illustrated in Fig. 23.

So, too, it must be clear that anything which checks the velocity of the wind across the top of a chimney or ventilating flue, or which resists the escape of air from them, must reduce the power of the wind to produce draft. Such caps, therefore, as are seen in Fig. 23 and as is represented on a larger scale in Fig. 24, designed to keep out the storm, must necessarily materially reduce the draft and should be avoided wherever possible unless forced ventilation has been adopted and the current is maintained by mechanical power.

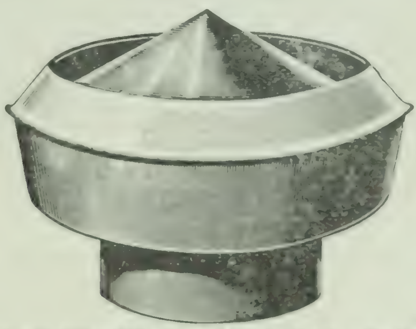

Fig. 24.—Shelter for ventilating flue, designed for high efficiency in keeping out rain but which materially reduces the draft in "natural ventilation."

Many forms of cowls have been devised to prevent downdraft in chimneys and ventilating flues, and with a view to utilizing the wind to better advantage in producing draft. It will seldom happen, however, that these need be resorted to in the ventilation of ordinary farm buildings or rural schoolhouses or churches. One of the mistakes most often made in installing a ventilation system in barns is illustrated in Fig. 25, where a one-story barn is provided with

short ventilating flues which, because they are short, have a low efficiency and then this efficiency is still further reduced by covering the outlet with closely louvred shelters which materially diminish the effect of the wind in aiding ventilation.

Fig. 25.—Low ventilating flues having their efficiency much reduced by closely louvred shelters, diminishing the effect of the wind in producing draft.

A much better construction for the ventilating shaft is represented in Fig. 26 where the flues are not only higher but the outlet is shielded in such a way as not to materially impede the movement of the passing wind or the escape of the air from the ventilating flue.

Any condition or cause which changes the density of the air in a dwelling or stable, rendering it lighter than an equal volume outside, tends also to establish and maintain a current of air flowing through it. The effect of both heat and the addition of moisture to the air of a room is to render it relatively lighter than the air outside and so long as a difference in density is maintained there is a difference in pressure which tends to compel a continuous flow of air into and out of the space.

When air is warmed or cooled its volume changes $\frac{1}{491}$ for each degree F. rise or fall in temperature. Imagine a

room containing 491 cubic feet, one very nearly 8 by 8 by 8 feet. If the air in this room has its temperature raised one degree F. the expansion so caused will force out just one cubic foot of this air and so, if the temperature is raised 100 degrees, there will be forced out of such a room 100 cubic feet and the air remaining will weigh about 8 pounds less than an equal volume outside. This being the case there must result a pressure inward tending to force air into the

Fig. 26.- Ventilating flues rising high above the roof and with outlet sheltered so as to permit free wind movement and easy escape of air from the flues.

room, a pressure equal to about .08 pound for each degree difference in temperature, and hence 8 pounds where the difference is 100° F. Referring now to Fig. 27, which represents a room of 491 cubic feet capacity, suppose there is an opening of one square foot area in the floor at A and an equal similar opening in the ceiling at B. If the air in this room is maintained at 70° when the outside air is 30° below zero its weight will be 8 pounds less than that of an equal volume outside. This being true the pressure into the room at the floor and on sides and ceiling must be 8 pounds greater than that exerted outward by the inside air; and since the floor has an area of nearly

• 8 × 8 = 64 sq. ft.

the pressure tending to force air into the room at the floor opening and out at the ceiling must be one sixty-fourth of 8

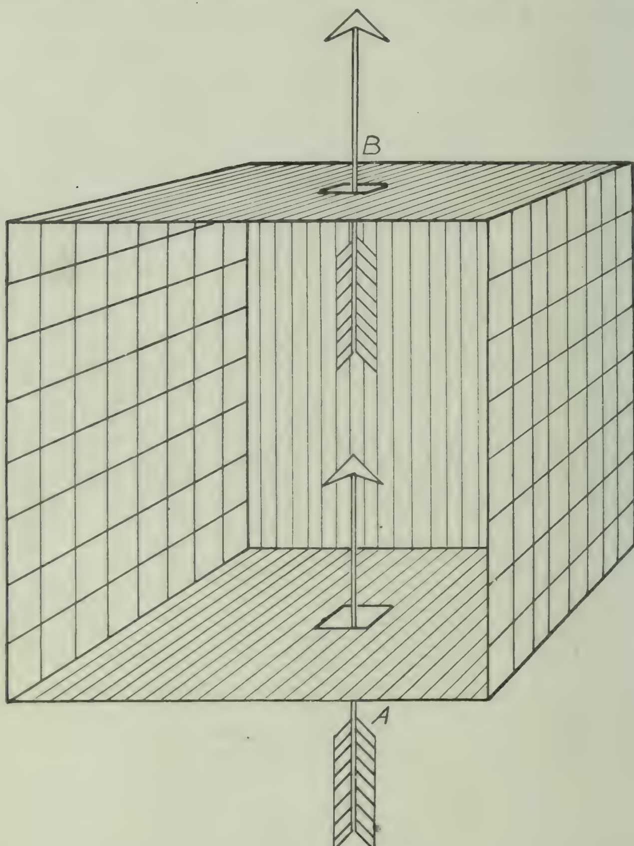

Fig. 27.—Difference in temperature as a motive power in ventilation.

pounds, or .125 lb. per square foot. This too is the difference in weight between a column of air one square foot in section the hight of the room and an equal column outside. So long, therefore, as such a difference in temperature is maintained air must tend to enter at the floor and flow out at the ceiling at the rate which a pressure of .125 pound

per square foot is capable of maintaining, which theoretically is more than 25,000 cubic feet per hour.

The magnitude of the temperatue effect in producing draft is given by the equation.

$$\text{Cu. ft. per hour} = 60 \times 60 \times 8 \sqrt{\frac{T - t}{491} H}$$

where

60×60 is number of seconds per hour:

8 is $\sqrt{2g}$, and g is the increment of gravity, 32.16;

T is temperature of the air inside;

t is temperature of the air outside;

H is height of room, chimney or ventilator:

$\frac{1}{491}$ is the expansion of air for 1° F.

Suppose a ventilation flue one square foot in section 40 feet high, and the air in it maintained at a temperature 20° above the air outside. In such a case the theoretical flow through the flue would be 18,381 cu. ft. per hour.[1]

This is the theoretical rate of flow, no account being taken of friction or other forms of resistance. The actual flow which would be associated with such a difference in pressure might be fully 50 per cent less than this.

The effect of temperature differences in producing draft increases with the hight of the chimney, ventilating flue, and with that of the room or stable. It is because of the greater leakage of warm air from rooms and stables with high ceilings that it is more difficult to keep them warm. This will be readily seen from a consideration of the problem presented in connection with Fig. 27, considering the room to have a hight of 16 instead of 8 feet. Such a room would contain twice the volume of air and hence, with the same increase in temperature, the expansion would cause an escape of 16 instead of 8 cubic feet of air. The air of the room would then be lighter than an equal volume of that outside by the weight of 16 instead of 8 cubic feet, and hence there would be double the pressure forcing the air to enter and leave the room. Computing the theoretical

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[1] $60 \times 60 \times 8 \sqrt{\frac{20}{491} \times 40} = 18381$ cu. ft. per hour.

change of air in the two rooms we shall have for the one with the 8-foot ceiling 36,760 cu. ft. per hour,[1] and for the room with a 16-foot ceiling the rate of air change would be 51,889 cu. ft. per hour.[2] If the two rooms under consideration were not provided with special openings for the entrance and escape of air, as represented in Fig. 27, and the air was required to enter entirely through leaks in the walls, approximately the same relative changes of air would take place and it is clear that it is much more economical, both in cost of construction and in that of maintaining proper temperature to place the ceilings of dwellings and stables only so high as is needful to secure convenience and sanitary conditions; aiming to secure the necessary rate of change of air through definite provisions in the way of ventilation. It is clearly much cheaper to construct a tall ventilating flue for securing the necessary increase in the rate of air change, than it is to make the walls of rooms and stables higher.

In the table which follows there are given the theoretical rates of flow of air through ventilating flues of different hights and under several differences of temperature maintained inside and outside the flues.

Computed theoretical flow of air through straight ventilating flues one square foot in cross-section, of different lengths and under 8 temperature differences. The observed flows are likely to be near 50 per cent below these values.

Difference in temp. T–t.	Height of ventilating flue, H.				
	20 ft.	30 ft.	40 ft.	50 ft.	60 ft.
	Flow, cubic feet per hour.				
1°...........	5.828	7.138	8.242	9.215	10,095
10°...........	18.409	22,572	26.064	29.114	31,922
20°...........	26.064	31.775	36,680	41.211	45,144
30°...........	31.922	39.096	45.144	50,472	55,291
40°...........	36.902	45.144	52,128	58.214	63,843
50°...........	41.211	50.472	58,214	65,159	71,378
60°...........	45.144	55.291	63.843	71.378	78,192
70°...........	48,761	59,920	68,958	77,098	84,457

[1] $60 \times 60 \times 8 \sqrt{\frac{100}{491}} \times 8 = 36760$ cu. ft. per hour,

[2] $60 \times 60 \times 8 \sqrt{\frac{100}{491}} \times 16 = 51889$ cu. ft. per hour.

The relation between wind velocities and the pressures due to impact and to suctional effect are given in the next table, together with the flow of air computed, using the formula on page 55, where the wind pressures in the third and sixth columns have their temperature difference equivalents computed and given in the fourth and seventh columns, these being used with the formula named.

Computed theoretical flow of air through a flue one square foot in cross-section and 40 feet long, due to the direct impact and suction effect of wind at different velocities.

Velocity of wind.		Direct impact.			Suctional effect.		
Per hour. miles.	Per sec., feet.	Pressure. Inches of water.	Equivalent as T–t. degrees.	Flow per hour. cu. ft.	Pressure. Inches of water.	Equivalent as T–t. degrees.	Flow per hour. cu. ft.
1..........	1.47	.001	.77	7.201	.0005	.41	5.272
2..........	2.93	.0039	3.07	14.402	.0021	1.64	10.545
3..........	4.40	.0087	6.90	21.603	.0047	3.69	15.817
4..........	5.87	.0155	12.26	28.804	.0083	6.56	21.089
5..........	7.33	.0242	19.17	36.005	.0130	10.24	26.362
6..........	8.90	.0349	27.59	43.205	.0187	14.75	31.634
7..........	9.87	.0475	37.56	50.406	.0254	20.08	36.906
8..........	11.73	.0620	49.06	57.607	.0332	26.23	42.178
9..........	13.20	.0785	62.09	64.808	.0420	33.19	47.451
10..........	14.67	.0969	76.65	72.009	.0518	40.98	52.723
11..........	16.13	.1172	92.75	79.201	.0627	49.59	57.995
12..........	17.60	.1395	110.38	86.411	.0746	59.01	63.268
13..........	19.07	.1658	129.54	93.612	.0875	69.25	68.540
14..........	20.53	.1903	150.54	100.813	.1015	80.32	73.812
15..........	22.00	.2082	172.62	108.014	.1166	92.20	79.085

If the flow of air through a ventilating flue 40 feet high and one square foot in cross-section, as given in the two tables, is compared it will be seen that differences of temperature inside and outside the flue ranging from one degree to sixty degrees F. are associated with computed air movements increasing from some 8,000 cubic feet with a difference of one degree F. to 63,000 cubic feet per hour when the difference in temperature is 60° F.; while wind velocities ranging from one mile to nine miles per hour, acting by direct impact, and of two miles to twelve miles per hour acting by suction, give approximately equal rates of flow. If the actual velocities were one-half these computed amounts the slowest rate of movement would a little more

than meet the needs of one cow while the most rapid movement would permit a flue one square foot in cross-section to supply nine cows at the rate designated on page 41, 3,542 cubic feet per hour. Such a rate of movement, too, through a flue one-fourth of a square foot in cross-section would, at one half the slowest rate, supply air to 2 persons, and, at one-half the fastest rate, to 15 persons.

The wind velocities which are effective in producing draft in dwellings and stables probably do not have a yearly average in most parts of the United States greater than four to six miles per hour. Taking the average flow due to impact equal to that computed for the four mile wind, and that due to suction equal to the computed value for a six mile wind, and supposing further that these effects are fully additive, the mean flow due to wind action would be some 60,000 cubic feet per hour, one-half of which may be lost in overcoming unavoidable resistance, thus leaving 30,000 cubic feet per hour of effective flow, which is sufficient to meet the needs of more than eight cows.

The temperature difference effective in ventilation, not including heated chimneys, is perhaps not higher on the average than 20° F. for stables nor than 50° for dwellings, the first difference being capable of producing a flow of 36,000, and the second 58,000, cubic feet per hour in a 40 foot flue one square foot in section. If this motive power due to difference in temperature be added to that derived from wind action the resulting flow would be some 96,000 cubic feet of air per hour for stables and 120,000 for dwellings, having in mind theoretical flows and a ventilating flue 40 feet high and one square foot in section. Dividing these results by two, to allow for loss of power in overcoming resistance, the remaining motive power should be capable of producing a flow of 48,000 cubic feet per hour for stables and 60,000 for dwellings.

In his "Air Currents and the Laws of Ventilation" Shaw cites experiments wherein the observed velocity of flow through 3-inch metal flues about 25 feet long varied from 7,482 feet per hour, when the wind velocity was at the rate

of 2.5 miles, to 20,064 feet when the velocity of the wind was 15 miles per hour. The observed flow associated with a wind of 4 miles per hour in these experiments was 8,448 feet, and with 6 miles, about 10,000 feet per hour. At the 4-mile rate of flow a square-foot flue would meet the needs of only 2⅓ adult cows, and the 6-miles rate, not quite 3 cows. In these trials all resistance is taken into account, the flows being actual, but in ordinary ventilation there would be added the temperature effect which might nearly double the efficiency.

In the dairy stable of the Wisconsin Experiment Station, represented in Fig. 53, page 112, with a ventilating flue rising 60 feet above the floor and with the main shaft 40 inches in diameter, the observed flow of air during one week was as follows:

1st day	205,377 linear feet
2nd day	205,800 linear feet
3rd day	247,852 linear feet
4th day	242,854 linear feet
5th day	151,974 linear feet
6th day	132,822 linear feet
7th day	153,720 linear feet

Here is an observed average velocity of air through the main ventilating flue of 7,978 feet per hour. In this stable, however, there are but 10 fresh-air intakes, each with an area of 3 by 12 inches and each of these is covered with a register face which reduces their efficiency to some extent so that the aggregate area for fresh air intakes is less than 2.5 square feet. The walls and the ceiling of the stable are covered with galvanized iron and therefore practically air-tight except for leakages about doors and windows. If all of the air passing through the ventilating flue had entered the stable through the fresh-air intakes the velocity through them must have exceeded 27,000 feet per hour which, with a flue one square foot in cross-section, would supply nearly sufficient air for 8 cows.

In the four stables of H. McK. Twombly, Fig. 26, page 53, at his Florham Park farms, New Jersey, in July, when the cows were out after milking at night, with a wind movement outside near the ground less than 50 feet per minute,

the rate of air movement was found to be as recorded below:

	Doors and windows open, per hour.	Doors and windows closed, per hour.
	feet.	feet.
Stable No. 1	11,040	8,620
Stable No. 2	7,740	7,860
Stable No. 3	8,340	9,180
Stable No. 4	8,640	6,960
Average	8,940	8,160

The ventilating flues in these stables were 30 feet high, of galvanized iron; 4.5, 3.5, 3 and 5.5 square feet respectively in cross-section, there being two for each stable. It will be observed that in this case the velocity of discharge through the ventilating flues averaged somewhat less with the doors and windows closed although the cross-section of the fresh-air intakes aggregated 6, 4.3, 4.6 and 6 square feet for the several stables, rather more than the cross-section of the ventilating flues. These intake flues, however, were covered outside and in with register faces which reduced their effective cross-section probably below that of the ventilators themselves. Under these conditions the available motive power for ventilation was probably near its minimum for the air near the earth's surface outside was almost calm and the cattle were out of the stable so that the only available heat for ventilation was the little that may have been retained by the walls to be given out during the night. Notwithstanding the low available motive power the wind movement through the ventilation flues was sufficiently rapid so that a current a square foot in cross-section was 2.5 times that needed for one cow.

The influence of moisture as a motive power in ventilation is measured by the effect the amount transpired or otherwise added to the air has in making that within the space to be ventilated lighter per cubic foot than that outside. Take the case of air outside at 30° and weighing .08107 pound per cubic foot entering a stable, becoming charged with moisture to the extent of saturation at 45°

and having its temperature raised so as to remain at 50° when in the ventilating flue. Air so changed will be reduced to a weight of .07747 pound per cubic foot, thus giving rise to a motive power in a ventilating flue 40 feet high equal to .027 inch of water,[1] and this pressure reduced to its equivalent value in temperature becomes 21.8° F.[2] This value, 21.814° F., represents the combined effect of change in temperature and change in moisture content of the air. As the change in temperature between 30° and 50° is 20° the moisture effect must have a temperature equivalent of 1.8° F. This temperature equivalent, acting as a motive power, or aeromotive force, as it has been called, is capable of producing a theoretical flow in a 40 foot flue of 11,073 cu. ft. per hour.[3] The motive power derived from moisture added to the air of a ventilated space is always operative in assisting ventilation and its magnitude is the greater the more completely the air is saturated, the higher is its temperature and the longer the ventilating flue. In order, therefore, to most fully utilize the effect of moisture as a motive power in ventilation it is necessary to construct warm stables and to so place the ventilator that its walls may remain as warm as practicable, thus avoiding condensation of moisture before leaving the flue.

It not infrequently occurs that the motive force due to wind pressure and wind suction is very small or even zero. We have found, for example, that at Madison, at the laboratory very near the shore of Lake Mendota, where the wind movement was measured at an elevation of 120 feet above the lake and 82 feet above the ground, there were 16 days

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[1] $\frac{(.081074 - .077472) \times 40}{5.2017} = .0277$ inch water pressure

[2] $T - t = \frac{.0277 \times 491 \times 5.2017}{40 \times .081074} = 21.814°$ F.

[3] $60 \times 60 \times 8 \sqrt{\frac{1.814}{491} \times 40} = 11073$ cubic feet per hour.

in January when during the night, the time when stables are most tightly closed, the wind velocity did not average five miles per hour during any 10 consecutive hours between 7 p. m. and 7. a. m. On 10 of these nights the recorded wind movement during more than an hour was either zero or less than one mile. At such times as these dependence must be placed upon the motive power derived from rise in temperature and from an increase in the moisture content of the air after it enters the stable. It is important therefore to know what the minimum motive power from temperature and from moisture changes is likely to be as this knowledge is fundamental in determining the proper dimensions for the ventilating system.

As dairy stables will seldom need to be tightly closed when the outside temperature is above 30° F. and as at this temperature that of the stable is likely to be as high as 50° F. it may be assumed that the minimum motive power available for the ventilation of such stables is likely to be not less than that given when the outside air enters, saturated with moisture, at 30° and when the air leaves the stable at a temperature of 50° and containing only 3.3 per cent of air once breathed. Under these conditions the entering air would weigh .0809 pounds per cubic foot and before entering the ventilating shaft would be reduced by changes in temperature and composition to .0777 pound per cubic foot, thus giving rise to a motive power in a ventilating flue 40 feet high equal to .02461 inch water pressure, whose equivalent, expressed in difference of temperature, is 19.422° F. This difference in temperature is capable of giving a flow of 36.227 cubic feet per hour through a ventilating shaft one square foot in cross-section and 40 feet high. This value is the theoretical flow. Taking the effective flow equal to one-half this amount we shall have an hourly supply equal to 18.113 cubic feet or 301 cubic feet per minute. A velocity of 295 feet per minute in a flue 2 by 2 feet in cross-section will supply 20 cows at the rate of 3.542 cubic feet per hour and per head, and this is the amount needed, as previously stated, that the air of the

stable shall remain 96.7 per cent pure or shall contain at no time more than 3.3 per cent of air once breathed, the standard we have assumed as possibly permissible for dairy cows.

In the case of barns for sheep, piggeries and especially poultry houses, where lower differences of temperature are quite certain to occur, the motive power must necessarily be less when the wind movement is small. Besides, in these cases, it will seldom be practicable to construct as long ventilating flues hence relatively larger shafts must be installed or other equivalent means adopted for securing the desired change of air.

To make clear this fact let us assume a poultry house for the accommodation of 50 hens each needing 35 cubic feet of air per hour, as stated on page 41. The ventilating flue must therefore provide for 50 times 35 cubic feet, or 1,750 per hour. Let it be assumed that the ventilator has a length of 16 feet; that a temperature difference of only 4° is maintained in it when the outside temperature is 30° F.; and that the rate of air movement is to be such as to maintain a purity of 96.7 per cent with a moisture saturation at 34° of 90 per cent. With the outside air saturated at 30° and with the composition, page 13, its weight will be .0809 pound per cubic foot, and that in the ventilating shaft, at 34°, 90 per cent saturated and containing 3.3 per cent of air once breathed, having the composition of that stated on page 14, would weigh .08024 pound. This gives a difference of pressure between the air in the 16 foot shaft and that of an equal column outside of .00066 pound per square foot. Reducing this to its temperature difference equivalent it becomes .2504° F. Using this value to compute the theoretical flow the result becomes 2601.3 feet per hour, which, at half this value, leaves an effective flow equal to 1300.6 feet. But the 50 hens require 1,750 cubic feet of air per hour. The size of the ventilating flue must therefore be

$$\frac{1750}{1300.6} = 1.346 \text{ square feet.}$$

This area is given by a rectangular flue 14 inches on a side and by a circular one 15.7 inches in diameter.

MAINTENANCE OF TEMPERATURE WITH AMPLE VENTILATION.

It may appear that the movement of such large volumes of air through stables and dwellings as have been considered needful in ventilation is incompatible with comfort and economy as regards warmth. Let us see what are the facts: In the first place we need to understand that nearly all the food assimilated or utilized in the body, like fuel burned in the stove, gives rise to a certain amount of heat so that every animal and person is in a sense a heat generating mechanism. It is estimated that a cow produces and gives off from her body daily, as a result of changes taking place in the food she eats and air she breathes, an amount of heat equal to 76,133 British thermal units, heat sufficient to raise from 32° F. to boiling 423[1] pounds of water and it is enough to raise the temperature of 79,603[2] cubic feet of dry air from 0° F. to 50° F. Thus it appears that the heat generated by one cow during 24 hours is sufficient to warm approximately 79,600 cubic feet of air through 50 degrees F. or at the rate of 3,316 cubic feet per hour. This amount is only 226 cubic feet of air less than has been taken as possibly sufficient to meet the needs in dairy stables. It should be understood that during the winter in the United States only occasionally is the outside air at a temperature as low as 0° F. Indeed the mean temperature for Wisconsin for January is nearly 15° and a rise of 50 degrees above this would give a stable temperature of 65°. Taking Doctor Jordan's estimate of the heat given off by a cow daily equal to 76,133 British units, and 3,542 cubic feet of air per hour as the amount needful for each cow, and supposing that the whole of the

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[1] $\frac{76133}{180} = 422.96$ pounds of water,

[2] $\frac{76133}{50 \times .237 \times .08071} = 79603$ cubic feet.

heat so generated is lost through the air passing into and out of the stable, this heat is capable of warming the unit volume of air through 47.55 degrees F. and, on this as a basis, the following table is computed, showing approximately the temperature of stable air when it enters at different temperatures at the rate of 3,542 cubic feet per hour and per cow.

Approximate temperature of stable air resulting from animal heat, when entering at different temperatures at the rate of 3542 cubic feet per hour and per cow.

Temperature of outside air.	Temperature of inside air.
—32° F.	15.55° F.
—10	37.55
0	47.55
10	57.55
15	62.55
20	67.55
25	72.55
30	75.55

Of course some heat is lost in other ways than through the air entering and leaving the stable so that lower temperatures than those in the table must be expected under the conditions stated but, as the average winter temperature in the United States is materially above 10° it is clear that good ventilation for dairy stables is possible and yet permit reasonable temperatures to be maintained. As a specific example of temperatures actually maintained the table which follows is cited, wherein are given the mean daily temperature of the dairy stable at the Wisconsin Agricultural Experiment Station, during two weeks, together with the outside temperature, the total air movement through the stable and the cubic feet of air per cow and per hour, as observed by E. L. Jordan in a thesis study relating to the influence of temperature on milk production.

Mean daily temperatures and air movement through a dairy stable containing 31 cows.

Date.	Average Temperature.		Flow of air.	
	Stable.	Outside.	Total per hour.	Per cow per hour.
			Cu. ft.	Cu. ft.
January 13..........	56° F.	13° F.	83.621	2.697
January 14..........	49	13	86.965	2.805
January 15..........	50	20	80.591	2.600
January 16..........	50	14	83.522	2.694
January 17..........	47	13	85.596	2.761
January 18..........	47	18	89.768	2.896
January 19..........	54	28	88.435	2.853
January 20..........	51	27	81.578	2.632
January 21..........	50	25	105.107	3.391
January 22..........	48	21	92.317	2.978
January 23..........	47	— 2	83.479	2.693
January 24..........	43	—18	77.632	2.508
January 25..........	44	—16	81,882	2.641
January 26..........	44	—11	100.964	3.257

This table shows that with the outside temperature ranging from 28° to –18°, a range of 46 degrees, the stable temperature varied between 43° and 56°, a range of but 13 degrees, the temperature maintained entirely by the heat of the animals and this with a measured flow through the ventilating shaft at no time less than 2,500 cubic feet per cow per hour. In addition to this flow of air through the stable by way of the ventilator there was undoubtedly a material leakage through the windows and other openings which would carry the air supply well toward, if not above, 3,542 cubic feet, the standard assumed as possibly adequate.

The amount of heat required for warming the needed amount of air for good ventilation is not as great as might be expected from its large volume for the reason that it is very light and because its specific heat is very low, only .237 as compared with 1 for water, pound for pound. That is, it takes as much heat to raise a pound of water one degree as it does to raise 52 cubic feet of air through the same range of temperature. With hard coal at $10.00 per ton and of the usual fuel value; with the outside air at zero, to be raised to 72° inside, and supplying 10 persons during 24 hours at the rate of 537 cubic feet each per hour, only

11.26 pounds of coal would be required to furnish the needed heat, making the fuel cost but 5.63 cents per day for thus warming the necessary amount of air for 10 people. This statement must be understood as meaning that the extra amount of heat in house warming required for proper ventilation is but very little above that required where only poor ventilation exists. Stated in another way, to maintain the proper temperature in the house when the temperature outside is zero, without any ventilation whatever, requires a certain amount of fuel, this varying with the type of construction. To warm the necessary amount of air required for good ventilation during 24 hours would in reality cost less than 5.63 cents extra for 10 persons where coal is $10.00 per ton, because a part of this heat would also be available for maintaining the proper temperature. There is therefore little ground for providing insufficient ventilation because of extra expense needed for fuel. But in order that the maximum air movement through stables may be secured without the aid of artificial heat or mechanical appliances and that good ventilation for dwellings, schools and offices may be had without unnecessary cost it is important that, so far as possible, the exhaust should be from the coldest part of the room which will be usually the floor level.

There is a general impression that because respired air, before leaving the lungs at the temperature of 93° to 97° F. is lighter than pure air at room and stable temperatures it must rise at once to the ceiling and that for this reason ventilating flues should exhaust from that level rather than from the floor. The facts are that respired air so soon as it leaves the lungs and becomes cooled below 81° is heavier than pure air at the same temperature because of its increased content of carbon dioxide, the moisture it is capable of holding below 81° not being sufficient to compensate for the increased weight due to the carbon dioxide added. The fact will be made clear by an inspection of the next table.

Weight of a cubic foot of pure air and of air once respired by man at different temperatures.

Temperature.	Pure air composition. O 20.61% CO_2 .03% H_2O .55% N 78.81	Respired air composition. O 15.725 CO_2 4.350 H_2O 2.000 N 77.925
70°	.074316	.075223
64	....	Saturated
60	.075961	.076884
50	.077605	.078544
40	.079249	.080205
30	.080894	.081865
29.8	Saturated	....

Here it is seen that air changed in composition by being respired and cooled to temperatures between 70° and 30° is heavier than pure air at the same temperature. As soon as respired air cools below the temperature at which it becomes saturated by its contained moisture a portion of this must be condensed, leaving it heavier because of this loss of moisture. Thus, in the colume of respired air, it is seen that it becomes saturated at 64° and when it is cooled to 50°, instead of really having the weight there stated, on the basis that it could contain 2 volume per cent of moisture at that temperature, its actual weight when saturated is .078765 pound per cubic foot, which is 1.49 per cent heavier than pure air at the same temperature.

Fig. 28.—Inverted jar being filled with respired air.

That respired air, when surrounded by pure air, either rises very slowly or tends actually to fall may be clearly demonstrated. Let the Mason jar earlier used be inverted, Fig. 28, while air from the lungs is made to displace that which it contains. With the candle already lighted let the jar be at once lowered over it, Fig. 29. The flame is extinguished as it was in an earlier experiment when the candle was lowered into the jar filled with respired air. But if the trials are now repeated with the jar both inverted and placed with mouth up it will be found,

Fig. 29.—Respired air in inverted jar extinguishes flame if lowered over it quickly.

Fig. 30.—Respired air soon drops from the inverted jar and the flame is not extinguished.

Fig. 30, that with the inverted jar materially less time is required for the respired air to become so changed as to permit the candle to burn in it than is the case when the jar stands mouth up. This could not be the case did not the rspired air, cooled by the walls of the jar, become quickly heavier than that outside.

These experiments and statements are in apparent contradiction to the results of some analyses of stable air, as in the case in the dairy stable at the New York Agricultural Experiment Station, represented in Fig. 31, where Dr. Jordan found, as an average of analyses made on two different dates, results given in the following table:

Composition and temperature of air at the floor and ceiling of the dairy stable at the New York Agricultural Experiment Station.

	Ventilator working.	Ventilator closed.
Temperature of air.		
At ceiling	56.3°F.	64.4°F.
At floor	50.0	56.3
Difference	6.3	8.1
Composition, volume per cent.		
H_2O at ceiling	.4815	.525
H_2O at floor	.7198	.5465
Difference	.2383	.0215
CO_2 at ceiling	.5335	1.4
CO_2 at floor	.351	1.0335
Difference	.1825	.3665

These analyses of Doctor Jordan and those of similar import made by other analysts appear to the writer not in necessary contradiction with the statements made, and that they should not be thought to indicate that it would be better for ventiltors to exhaust from the ceiling rather than from the floor level. In the case of the New York stable it appears probable that the circulation of the interior air, as indicated by the arrows in Fig. 31, tends to carry the respired air directly to the ceiling mechanically, notwithstanding its greater weight, thus giving the observed distribution of products. It should be stated, to make the situation more clear, that the samples of air analysed were taken at the center of the stable between the two mangers and where there must necessarily be a material mechanical effect tending to maintain an upward current.

But whatever may be the truth relative to the distribution of products of respiration in dwellings and stables this we think, should hold in all good practice: *Maintain a sufficient air movement through dwellings and stables to insure the entire air content in every case being sufficiently pure for thoroughly healthful conditions.* It is hardly possible to make the air movement for ventilation too large so long as the temperatures are right and there can be no doubt that the largest air movement with proper temperatures is possible only when ventilating flues exhaust from near the floor level. It is important to remember, too, in this connection, that whether waking or asleep, whether standing, sitting or lying, the supply of air breathed must be drawn from near the floor level and that removing all air from this level compels the return of an equal volume to it.

To fully utilize the heat of dwellings and stables in economic warming and in securing adequate ventilation it is imperative that certain principles of construction and of admitting and of removing air should be adopted. Speaking here from the standpoint of stables, without artificial heat or forced ventilation, each animal must be regarded as a heater which is warming the air of the compartment in three ways: (1) by direct contact of the air with the body; (2) by rapidly breathing large volumes of it and raising its temperature at once to between 93° and 97° F.; (3) and by direct radiation of heat to walls, ceiling and floor which in turn warm the air by contact. Because the warmed air is thus rendered lighter it is forced at once to the ceiling where it tends to collect, while the coldest air, settling toward the floor, gives rise to an internal system of circulation represented by the arrows in Fig. 31. It will be seen from this illustration that the circulation of the stable air is maintained by the continuous action of three motive forces; (1) the waste heat of the occupants which becomes effective through its expansion of the air; (2) the mechanical or bellows-like action of the chests of the cattle and (3) the loss of heat by conduction through the outer walls.

Referring to the figure the arrows show that from the bodies of the cows convection currents rise directly toward the

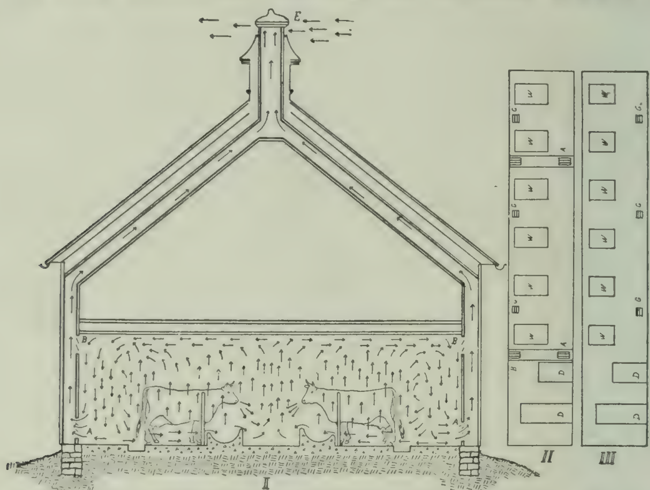


Fig. 31.—Section of cattle barn at New York Agricultural Experiment Station. I, illustrating convectional system of air currents maintained by the animals and the cooling of the outer walls. II, side elevation of stable viewed from inside, showing AA, floor entrance to ventilating flues; BB, ceiling openings to ventilating flues; GGG, ceiling openings to fresh air ducts; WWWWWW, windows, and DD, doors. III, side elevation of stable viewed from outside showing GGG, openings to fresh air ducts.

ceiling; that with the cows facing each other the bellows-like action of each row forces the air currents so formed to meet in the center and the air must rise and then flow outward along the ceiling in both directions, finally descending along the outer walls, at the same time mixing with the incoming fresh air entering at the several intakes GGG shown in the side elevations II and III. During cold weather and especially at the windows, unless they are double, and all along the walls if not of wood or hollow masonry, so as to be poor conductors of heat, the air will be cooled, thus rendering it heavier, causing descending currents which must flow along the floor, maintaining a more or less strongly marked system of air circulation within the stable, which tends continuously to mix the respired air with that entering from without.

From this tendency to the formation of a continuous circulation of air within the room to be ventilated it is clear that it must be extremely important that both ceiling and walls should be air-tight and warm in construction. With ceiling and walls tight and poor conductors of heat and with no opportunity for air to enter except where special provision is made, near the ceiling at GGG inside, II, Fig. 31, or for it to escape except at the floor level, only the coldest air is permitted to leave the stable, while at the same time the fresh air must be mingled with the warmest air of the stable, thus having its temperature raised before reaching the animals. Where such conditions of construction are secured the whole ceiling and upper walls become a continuous radiator of heat, sending back to the animals and to the floor, where it is most needed, the heat which has escaped from them. By admitting the fresh air from low down outside and at the ceiling inside, as represented in Fig. 32, this air entering from all sides as shown by the large arrows in Fig. 33, the cold incoming air is thus widely and generally mixed with the warmest air of the stable, thus having its temperature raised before being brought to the animals; while with the ventilating flues opening at A, Figs. 31 and 32, near the floor level, this arrangement not only compels the coldest air to be removed but it forces a return of the warmest air in the stable, mixed with the fresh air from outside, and thus partly warmed, to the floor level where it is needed both for warmth and for respiration.

So, too, in the ventilation of dwellings, offices and schoolhouses, as represented in Figs. 44 and 48, by admitting the fresh supply of air at the ceiling, where the highest temperature exists, not only is the heat being lost by updrafts through leaks utilized to warm the incoming air, but all drafts are avoided near the floor level, thus making it possible to have maintained the maximum air movement through the rooms without danger or discomfort.

Referring further to the method of admitting fresh air to stables, illustrated in Fig. 31 and 32, it should be understood that the position of the outside openings for the entrance of air to the fresh air ducts, placed at some distance below that admitting the air to the stable, is fundamentally important for the reason that only in this way can the escape of the warmest air of the stable through

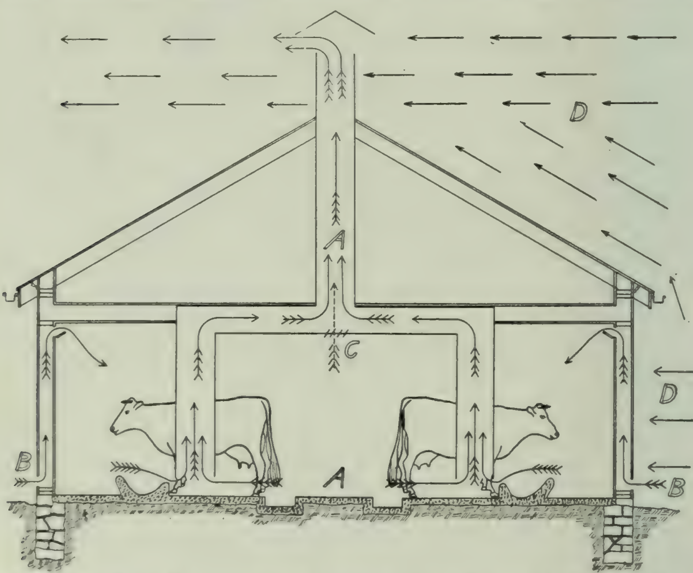


Fig. 32.—Section of dairy stable showing the action of the wind at DD, forcing air into the stable by direct pressure at BB and out of it by suction at the top of the ventilating shaft AA. At C is a ceiling register in the ventilating shaft to be opened only when the stable is too warm or when the draft is too feeble.

such openings on the leeward side be prevented. Without some such provision as this the case would be like lowering the windows at the top on opposite sides of stable or room, which always results in fresh air entering on the windward side and warm air escaping on the other. With the arrangement adopted, as shown in the illustrations, only a strong wind pressure can result in forcing the warm air to descend and escape through intakes on the leeward side.

The ventilation of offices which is so often attempted by raising a window at the bottom and inserting under it a screen carrying a pair of short Tobin tubes, like up-turned pipe elbows, while better than no attempt, can seldom give adequate ventilation where steam or hot water is used for warming for the reason that here provision only is made for air to enter and this can take place no faster than

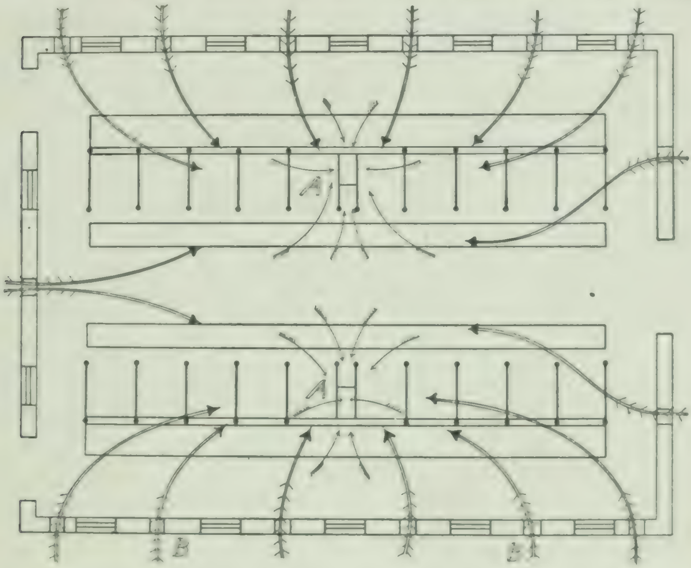


Fig. 33.—Floor plan of dairy stable, Fig. 32, showing fresh air intakes on all sides at the large arrows crossing the walls; two ventilating flues are AA and the air approaching them along the floor level indicated by the small arrows.

opportunity for escape exists. The opening of the door into a hallway or of the transom above it usually has only the effect of making the box to be ventilated larger; and the result usually is, with such makeshifts, that, on windy days during cold weather, such window openings are closed to save heat and during still weather there is little motive power to force an air movement if they are opened and hence much of the time very inadequate ventilation must obtain.

PRACTICE OF VENTILATION.

In coming to the practice of ventilation in cold climates the problem is reduced to its lowest terms when it is stated that the desired results can be ideally secured only when the construction of the building to be ventilated is such that no air can enter or leave it except at appointed places, and when all heat is lost through the outgoing air and none, or as little as possible, through the walls. While it is not practicable to construct enclosures whose walls are either air-tight or perfect non-conductors of heat it is nevertheless of the highest importance, as leading to correct practice, that right ideals be held and that they effectively direct construction. When nearly all air enters and leaves the space to be ventilated at the appointed places and when most of the heat is borne away during cold weather by the air leaving the room or stable there is secured the largest practicable rate of change and the most thorough ventilation, which is the object sought. Life under these conditions may live to its fullest capacity, rather than survive by the narrowest margin.

BEST ROOM AND STABLE TEMPERATURE.

The fires of life, kept alight through all the organs of the body by the incessant fanning of the lungs and the tireless pumping of the heart, can only be maintained between very narrow ranges of temperature. With ourselves and with all our domestic animals the temperature within the body lies close to 100° F. If the general active tissue temperature falls but a few degrees below this life activities must

cease; within the healthful but narrow range chemical changes go forward along normal lines and at the normal rate; at but a few degrees above this temperature reactions occur which seriously interfere with body functions, making them abnormal or causing them to cease.

Since most of the activities within the normal body result in the generation of more or less heat, and since the internal temperatures must be kept near 100° F., it is clear that surrounding temperatures must be at some lower degree than that of the body in order that a rate of loss of heat equal to that of production may take place. In our own case we become uncomfortable when the surrounding temperature rises much above 68° to 70° and the same is true of our domestic animals. Stables and dwellings then, as a rule, should have a temperature lower rather than higher than 70°, but how much lower than this is best must depend upon various conditions. Persons engaged in bodily exercise, and animals being heavily fed, like fattening swine, steers or sheep, are likely to do better in somewhat cooler quarters, (1) because the greater activity associated with increased assimilation must develop more heat and this must be removed at a more rapid rate, and, (2) because the aim in feeding such animals is to induce them to eat as much food as can be economically converted into the products sought, too warm quarters tending to make the need and desire for food less.

It has been found that when fasting and at rest, under a temperature of 90°, a man consumed some 1,465 cubic inches of oxygen per hour, but under the same conditions except that the surrounding temperature was 59°, 13 per cent more oxygen was consumed and a like increased volume of carbon dioxide thrown off, thus showing that more food must be eaten to compensate for the increased waste. But in eating more to maintain animal heat under lower temperature surroundings it is probable that more than enough to do this may be taken and hence that an increase in the formation of useful products will likewise result. When animals are simply on a maintenance ration and the aim is

to carry them with the least amount of food their quarters should then be as warm as the demands of health will permit. It seems likely that the best temperature surroundings for animals being fed high will be found to lie between 45° and 50°, while with animals on a maintenance ration these will be found to do better and to be maintained at a lower cost under temperatures between 55° and 65°. With dairy cows, having large udders only scantily clothed with hair, and through which so much blood must flow, it may be expected that a temperature perhaps as high as 50° to 60° will be found best, even with high feeding, although the few studies known to the writer, which have been made to determine this matter, have resulted in inconclusive data.

Because full comfort and complete satisfaction; ample and appropriate food and drink properly supplied; and sufficient unimpoverished and unpolluted air all of the time are the indispensable requirements for the highest animal production, and because we have never known an animal, however well fed, to voluntarily take to the open field in cold weather for rest, we are not yet convinced that a conveniently arranged and sufficiently warm shelter adequately ventilated is not indispensable to the highest results from winter feeding and winter maintenance.

LIGHT FOR DWELLINGS AND STABLES.

In the construction of every dwelling much care should be taken to secure an ample amount of light, in the kitchen, in the dining room and above all in the main living rooms. An abundance of light is needed not only to facilitate work but to make the best of intentions more certain in attaining results. Besides, it requires an effort to be gloomy and feel ugly in the face of a hearty laugh and a bright sunny, cheerful room has much the same effect upon those who occupy it. Many disease germs are enfeebled by direct sunshine or are destroyed by it. Who has not observed the cat deliberately seek out the sunny spot on the

carpet for the good feeling that comes with it and lasts after it. A sunny window is equally needed and enjoyed by the members of the family whose duties confine them so exclusively to the house.

The number, size and exposure of windows best suited to the requirements of dwellings and stables is not well established either in philosophy or in practice. It should go without saying, however, that sufficient window space must be provided to admit ample light for doing all necessary work with dispatch and efficiency and without an undue strain upon the eyes. How far beyond supplying such an amount of light it is best to go there is yet much room for difference of opinion, owing to the present state of knowledge, as to the efficiency of light of different intensities, as to the best manner of admitting light to dwellings and as to its importance in dwellings and stables as an agent in sanitation. So much is being urged upon the public at the present time, especially in the matter of lighting dairy stables, as a necessary measure of sanitation that it becomes a matter of practical moment to have the problem clearly and correctly stated, and the more so because efforts to secure unusual lighting are very likely to lead to deficient ventilation in dwellings and stables in all cold climates.

It has ever been and it must always remain true that the life resultants of every type are necessarily attained through compromises. Nature has never been an extremist along any line and all of her biologic assets have accrued through admitting in partial potency the multitude of factors always operative in securing the result, whether that be man, stamped with the highest attainments, or the deadliest microbe pitted against him. And so we are here confronted with the problem how much of light is most wholesome in the dwelling, and how much light may be admitted without unduly curtailing other essential requirements.

In the effort to put into practice the deductions of research and the recommendations of zealous but not always sufficiently informed teachers of stable sanitation many ser-

ious mistakes in construction are being made, one of which is illustrated in Fig. 34. This stable is far from the best type for use in cold climates. Thus constructed, the short, low closely-capped ventilators tend in themselves to provide but a small air movement. Then with the row of high deck

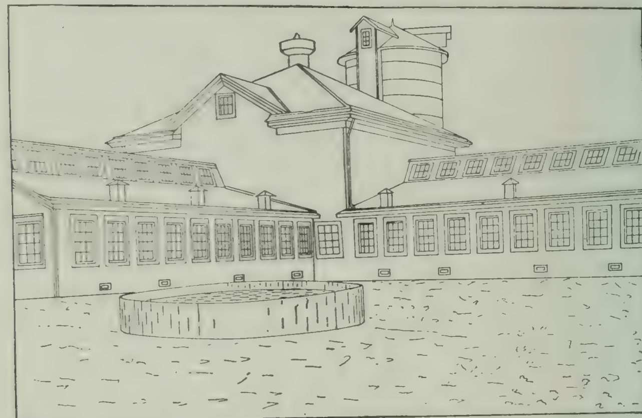


Fig. 34.—Showing faulty arrangement of windows for stables in cold climates, the effect being to render them cold and damp.

windows there is provided an elevated ceiling space into which the warmest air of the stable immediately rises, carrying with it the heat of the stable beyond where it can be utilized in warming the incoming fresh air, and where, because of great hight and unavoidable leaks, much of this warmest air must escape through the roof, tending furthermore to even carry fresh air direct from the intakes along the ceiling and out through the ridge, thus diminishing the lower ventilation. Such a stable, unless artificially heated, must either be very cold or have a small air movement through it. In either case the air must be damp and for this reason unsanitary. The side windows in this stable are excellent, both in dimensions and exposure, but, in our judgment six or seven, instead of ten, on a side, would have been ample.

If it shall be proven imperative to admit more direct and sky light into stables for the purpose of disinfection then some type of construction embodying the principle

represented in Fig. 35 must be adopted. In a type of construction like this, with double windows arranged along the slope of the roof, and with similar windows in the side both direct sunshine and reflected light from the sky may be admitted to the stable from all zones to the greatest practicable extent and at the same time utilize the animal heat in keeping the stable warm, thus permitting a maximum flow of air through the stable without unduly lowering its temperature or rendering it damp.

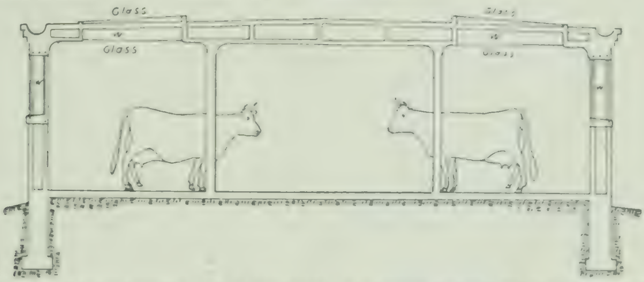


Fig. 35.—Cross-section of a concrete one-story dairy stable designed to admit the maximum amount of direct sunshine and of diffused light from the whole sky, leaving it at the same time warm in construction so as to permit the maximum air movement thus combining sunlight and desiccation to the greatest practicable extent as disinfecting agents.

It does not appear likely, however, that such extremes of illumination for either dwellings or for stables will be found materially better than moderate window space confined to the walls. It will not be maintained that, even out of doors where direct sunshine is at a maximum both in intensity and in duration and where the full hemisphere of reflected light from the sky is added, bringing illumination from every side, all disease germs which may there be present are destroyed by the light. Faced by this general truth relative to light as a destroyer of disease germs it becomes clear that even glass houses and stables cannot be expected to eradicate germ diseases. In dwellings and stables, far more than out of doors, shadows cast by litter and fixtures must effectually baffle all efforts to secure anything more than partial disinfection through the action of light whether coming direct from the sun or reflected from the

sky. The greatest safeguard against germ and all other diseases is found in a well nourished and well cared for body and as more than the half of such indispensable nourishment must be pure air, lighting beyond a fair amount cannot be permitted to seriously interfere with the air supply of stables or dwellings.

Dr. Weinzirl, of Washington University, whose has made recent critical studies along the line of light as a destroyer of disease germs and particularly those of tuberculosis, wrote, under date of Feb. 17, 1908, as follows:

"In reply to your question as to the value of sunlight in stable disinfection and the feasibility of this method I will say that in my opinion sunlight is of little value and practically of no value under prevailing conditions, nor do I believe that it can be made valuable by merely increasing the amount of diffused light through side windows. I exposed tubercle cultures on the window sill on north window for a week and yet about one-half of them grew. As to the other half I am inclined to think that desiccation, and perhaps other factors, entered to kill the culture. At any rate non-spore bearing bacteria are more readily killed by drying than is generally believed. A day or two will suffice to kill many of them."

In another letter Dr. Weinzirl qualifies the views as above expressed, writing under date of Oct. 19, after the other was in type. He says:

"I have made a good beginning on the problem of importance of diffuse light and as a result of this work I have to revise my views quite materially.

The shortest time in which diffuse light in a room killed the bacillus of tuberculosis was less than a day and the longest time was less than a week; generally, three or four days of exposure killed the organism.

Some pus-producing bacteria required a week's time to kill them, while some intestinal bacteria were killed in a few hours. It was also found that bacteria are killed more quickly in a moist air than in a dry one, contrary to general belief.

The diffuse light as found in our dwellings is, therefore, a hygienic factor of great importance, and where direct sunlight is not available, it should be carefully provided for."

It may be added as supplementary to Dr. Weinzirl's letter just quoted that he also made at the same time control exposures in the dark which showed, for the six groups of trials made between March 3 and July 2, and on as many dates, that no growth took place after intervals varying from 2 to 10 days, the exact times after which all germs were dead, or after no growth was observed, being 10, 7, 8, 9, 2, and 5 days respectively while the corresponding times for the diffuse light were 5, 3, 5, 6, 1, and 4 days. The averages of these two groups of intervals stand in about the ratio of 7 to 4, which means that under the conditions of exposure adopted and the method of testing viability the life of tuberculosis germs was rather less than 4 days in diffuse room light and that in the dark their life was less than 7 days. But it would be very misleading to leave light as an agent of disinfection with the reader thus stated. It should be understood that direct sunshine is far more potent in destroying disease germs than is reflected light and that that from the noon sun is stronger than the light coming from it earlier or later in the day. Most important of all to remember, for the direction it should give to practice, is the fact that even in the brightest sunshine the slightest shadows materially cut down its power to destroy germ life, so that under the hay and bedding of the stable and especially in the dung, where germs may abound, effectual darkness may obtain where the direct sunlight of noon is falling. Here is the kernel: Utilize to the fullest practicable extent every available agent of destruction, but remember that in every infected stable and home although millions of germs may be destroyed multitudes will escape and the losses will be made good from the springs of life. Remember, too, it is within the body, where effective darkness always prevails, that injury is done if it is powerless to resist, hence no amount of sunshine can compensate for the

diminished bodily vigor which results from insufficient ventilation, or other food supply.

It is important to understand something of relative intensities of the light received from the sky from different quarters and of that direct from the sun compared with that from the sky. Dr. C. G. Abbot of the Smithsonian Institution and Director of the Astro-physical Observatory, has determined the relative intensities of sky light coming from different elevations above the horizon from Mount Wilson at the time of clear sky in August and September with results given in the table below:

Average brightness of the sky at different distances above the horizon.

Altitude.	Relative intensity.	
0° to 10°	460	4.00
10 to 20	210	1.82
20 to 30	185	1.61
30 to 40	150	1.31
40 to 55	128	1.11
55 to 75	122	1.06
75 to 90	115	1.00

This table makes it appear that windows taking light from near the horizon may receive nearly four times the amount of that coming from directly overhead supposing the windows vertical in the first case and horizontal in the second and no obstructions whatever in either instance. As to the relative intensities of sky light coming from the south, east, north or west Dr. Abbot writes as follows under date of Oct. 28, 1908:

"I regret that our observations on the sky have not been conducted excepting on Mount Wilson, and that they are scanty even there, so that my replies to your questions cannot, I fear, be very satisfactory to you.

I feel sure that most light will be received from the sky if the stable windows face south (obstructions of course being absent). East and west will be nearly alike in this respect, but in most sections west will receive more than east. North is least favorable.

Less sky light will be received at high altitudes above sea level and at very clear localities than at low and hazy stations.

The horizon is much brighter than the zenith so that

where trees and hills do not obstruct the view the windows would receive most light I suppose if they were horizontal rather than vertical in their longer dimensions. I incline to think that horizontal windows adapted to receive light from the horizon to 30° altitude with unobstructed southern exposure would receive as much as four times the light equally large vertical windows with north exposure and adapted to receive light from 30° to 90° altitude would admit. But this is not a computation and is not applicable to all latitudes and altitudes above sea level, but is only intended as a probable estimate to suit average conditions in the United States. In winter the advantage of horizontal southern windows is greater than in summer.

As to the disinfecting qualities of the sky light at different zenith distances I know nothing. It seems probable to me, however, that if any such qualities exist in zenith sky light they would be found in at least equal and probably in greater total amount (not percentage), in the horizon sky light.

I do not know whether the disinfecting properties of light are cumulative as the photographic action is, or far greater if the light is very intense like the rise of temperature of a body in the focus of a lens. If the former is the case I should have little question that the continued action of sky light would be preferable to the brief action of sunlight. The whole sky at sea level is apt to contribute nearly as much light as the sun, and by far the larger proportion in middle northern latitudes comes from the southern half of the sky.

The above opinions are presupposing a generally clear sky. If the sky is most of the time cloudy, southern exposure would still be preferable but the horizon would, I think, cease to be the best part of the sky."

If Dr. Abbot's views thus tentatively expressed shall be found correct stables and dwellings should be lighted as far as practicable from the south for the reason that both direct sunshine, in the middle north latitudes and the maximum amount of sky light may thus be obtained. In the eastern part of the United States, east of Kansas, the aver-

age per cent of sunshine, computed on the total possible, is near 56. Taking this in connection with the fact that generally a considerable portion of the horizon to an altitude of 10° is obstructed we are inclined to favor windows with their long dimension up and down. The difference will be made clear from a study of Fig. 36, where it is seen that the point A on the floor receives sky light through the window E from between 20° and 50° above the horizon while from the window W, having half the vertical height, light comes in between 20° and 35°. If the lower light is most intense the last window will admit the most sky light, but if the higher light is best then the former window is to be preferred, from the standpoint of sky light. With the high window, as seen at C and B, direct sunshine must sweep a materially broader floor area than if it is short.

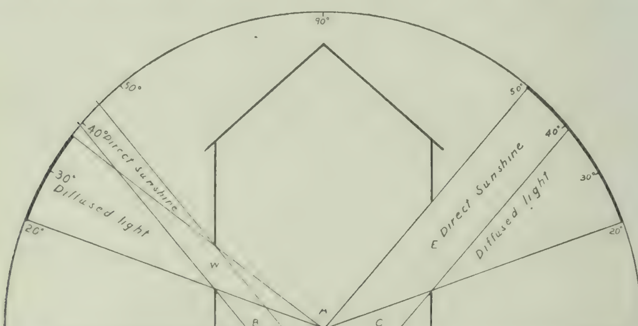


Fig. 36.—Influence of hight of windows on the admission and distribution of light in a building: B, C, area of direct sunshine; heavy arc of circle subtends angle of diffused light falling at A.

In low stables with wide overhanging eaves, and where windows are under porches, the same area of glass admits very materially less light, as is evident from an inspection of Fig. 37. The overhanging eaves at A, it will be seen, cut out half the direct sunshine and at the same time materially prevent the entrance of diffused light from the sky. From the other side of the building, where the eave does not overhang so far, both the quantity of direct and of re-

flected light are seen to be materially increased over that entering the opposite window, as shown by the length of

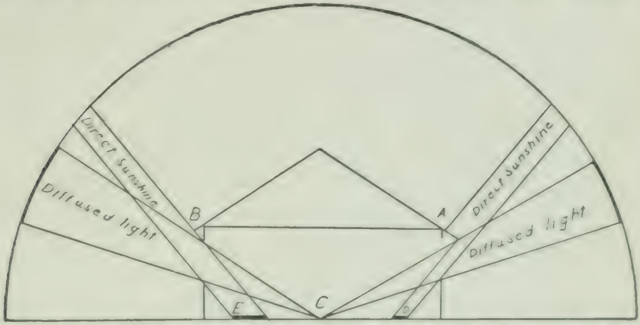


Fig. 37.—Effect of overhanging eaves and porches in reducing the efficiency of windows.

the direct sunshine areas D and E and by the size of the angles of diffused light falling at the point C.

It should be remembered too that where the walls of a building are thick relatively larger windows are required to secure the entrance of the same amount of light, the fact being made clear by a study of Fig. 38. The window at F,

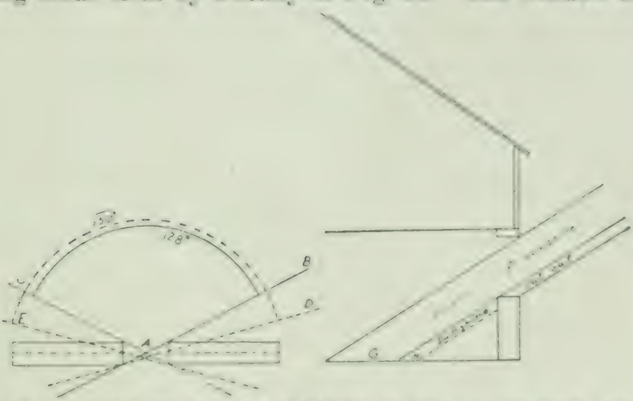


Fig. 38.—Showing the effect of thickness of wall in reducing the efficiency of windows.

four feet high in a wall one and a half feet thick, has its direct sunshine efficiency reduced nearly one-fifth by the thickness of the wall, as shown by the area marked H,

"sunshine cut out," with a width for this window of three feet, as shown at A, and with a thickness of wall of 18 inches, the angle at which sky light may enter is reduced from 180° to 128°, while a wall of half this thickness reduces the angle for diffused light only to 150°. With larger windows for the same thickness of wall the percentage loss of efficiency is less. In the case of direct sunshine the drawing represents the smallest possible reduction with the sunlight entering at the angle represented, the building being supposed to face the south with the sun at noon. At any time before or after noon, with the same altitude of the sun, a still greater reduction than that represented must take place.

VENTILATION OF DWELLINGS.

It is safe to say that before the close of another hundred years a very large proportion of the dwellings now in use will have been entirely rebuilt or extensively remodeled and that it is now none too early to begin a campaign of education which shall lead to the rebuilding or remodelling of those dwellings along lines which will make them thoroughly sanitary, convenient, pleasant and capable of being economically maintained in all of the ways which can contribute to substantial home comfort and character building.

It is also safe to say that at least two more generations will be compelled to grow up in the dwellings now in use but which are far less sanitary, from the standpoint of adequate ventilation than were those of the grandparents of the children now sixty. Then, in whatever other ways those homes may have been deficient, there was continually moving through them an abundance of undiluted and unpolluted air. The wide-open throat of the great fireplace of those days, which never could be closed, was everlastingly sucking out of the few rooms and in through the chinks in the wall, great volumes of air such as few people living in modern dwellings can realize. Today, with windows double; with walls sheated inside and out, sided, plastered and papered, on retiring we close everything

tight, even to the heater and kitchen range, and wake the next morning from troubled slumber hoping that, whatever else may not have been for the best, we have at least saved a little of the $9.50 per ton coal. Clearly if the two generations which must dwell in the old homes can be led and helped to better conditions of living in them great present and future gain will result. The vast throng of victims annually and prematurely wilting and fading away before the dreaded white plague meet disaster, not so much because of the great numbers and wide-spread distribution of the disease germs, as because of the terrible prevalence of such living conditions for cattle and people alike as convert the weak among them into hotbeds for the breeding of tuberculosis germs. Disease-germ-bearing milk is only one of a thousand vehicles by which these germs are spread and helped to gain a new foothold. If we shall ever succeed in greatly reducing the numbers of its victims it must be through fortifying the individual, rendering him capable of resisting the development of the disease germs even if they are introduced into the system, and this must come through more wholesome conditions and habits of living.

It cannot be too forcibly impressed upon the management of households that when one's duties are such that much of the time is spent in the open air, or that one is out and in frequently, the consequences that follow inadequate ventilation are likely to be far less serious than upon those confined more exclusively to the house. It should be remembered too that the person whose system has just been thoroughly renovated by breathing an abundance of fresh air is less sensitive to, except for the moment, and can safely endure, degrees of air pollution which may be oppressive and dangerous to those continually confined to inadequately ventilated rooms. And so it often happens that the menfolk of the farm are living fairly well, while the women in the same home may be suffering severely, especially during the winter, for lack of proper ventilation. Thought and judgment, therefore, exercised in the house as well as in the barn, is necessary.

Ventilation of Houses Already Built.

When the heating of the house is by means of stoves placed in the living rooms a certain amount of ventilation is secured through the direct action of the stove, for all of the air which enters the stove and leaves the room through the chimney is drawn into the house, through chinks in the walls where no special provision for entrance is made, and so long as the draft of the stove is open there may be sufficient ventilation for the time but so soon as the draft is closed and air ceases to escape through the stove, inadequate ventilation is likely to result. Suppose it is in the evening and five of the family are gathered about the table in a room 15 by 15, with a 9-foot ceiling and that they are using a lamp whose power to vitiate the air is equal to that of 10 candles such as used in Fig. 13. There would then be a consumption of air in the room equal in amount to that demanded by nine or ten people. We have found the ordinary student-lamp to burn kerosene at the rate of 38.4 grams per hour and this demands oxygen equivalent to more than six people, so that it is safe to say that, with five people and such a lamp, air is needed for the equivalent of ten people, and this demands an air movement, to maintain the standard of purity which we have assumed as possibly permissible for dairy stables, equal to 5,370 cubic feet per hour, which requires the room to be emptied of all its air and refilled once about every 22.6 minutes. It will be readily seen from this statement of fact that whenever the room becomes a little too warm, so that the drafts in the stove are all closed, such a room, not otherwise ventilated, would very soon become unsanitary from the standpoint of pure air. Indeed, with no interchange of air, in one hour nearly one-tenth of the whole air of the room would have been used once, and in once-breathed air we have seen the candle extinguished.

Let us see now what the stove can do for us in the way of ventilation when the drafts are open. Suppose the

chimney is 30 feet high and the air in the chimney is maintained at a temperature 50 degrees above that of the air outside. From the table, page 56, the theoretical flow through a one-foot square chimney 30 feet high is 50,472 cubic feet per hour. With half this efficiency, to allow for resistances to be overcome, and taking the cross-section of the 6-inch stovepipe through which the air must all go, at .2 of a square foot, the air movement which could be maintained is at the rate of 5,047 cubic feet per hour, which is a little less than 5,370 cubic feet, the movement we have assumed as possibly permissible. This reasoning and calculation makes it clear that whenever a room thus ventilated has the drafts in the heater closed the necessary air movement must at once fall below good living conditions and hence that some provision ought to be made for keeping up the air supply whenever the heater is not running with open drafts. There is often a check-damper in the stovepipe or stove which may be opened when the drafts are closed and so partly, at least, keep up the air movement. Such openings, however, as usually placed, are wasteful of heat because they throw out of the room only the warmest air. To economically use the room heater as a ventilating device there ought to be attached to the stovepipe, as represented at C in Fig. 39, a section extending down to near the floor level, provided with a close-fitting damper, so that whenever the drafts are closed in the stove the damper in the ventilating section may be opened, and thus keep up the air circulation, drawing out of the room only the coldest air it contains. Here, then, is a simple arrangement by which many a poorly ventilated home may have its sanitary conditions very materially improved, at a trifling expense when compared with the advantages gained. If the room to be ventilated is tightly constructed and if air cannot be borrowed from another unoccupied room by leaving the door ajar, there is no reason why fresh air intakes may not be provided on the same plan as has been illustrated for dairy stables in Figs. 31–32, pp. 72–74, and which is represented at AAAA, BB, in Fig. 39. In providing such in-

takes it is only necessary to make openings through the siding, as represented at A, between pairs of studding, covering them with one-eighth inch mesh galvanized wire netting, and make corresponding openings just under the ceiling at the same pair of studding, covering these with white enameled 4 by 12-inch register faces.

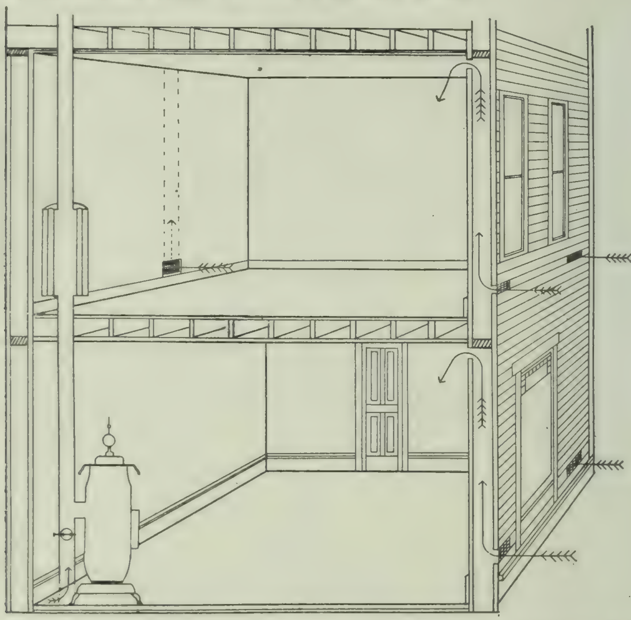


Fig. 39.—Improvised ventilation system for an ordinary dwelling already built.

The proper course to take in installing such a ventilation system is to modify the heater so that air may be removed from the floor level as already described. If it is then found that an air change of sufficient rapidity takes place, this being made possible through unintentional openings in the wall, the desired result has been attained and the intakes need not be provided. It may be that a sleeping room is situated as represented in the illustration, through which the stovepipe passes. If so it is a simple matter to attach a radiator to the pipe and thus without extra expense ma-

terially warm the room and improve its ventilation if only a ventilating flue is installed as indicated at D. In this case we have assumed that there is a partition and that the space between a pair of studding may be opened just above the baseboard and covered with a white enameled register face, or better still, a register which may be opened and closed, and then open this space into the attic or, what would be much better, extend up through the roof a six-inch galvanized iron pipe, connecting this with, or extending it down into, the space between the studding leading to the ventilating register. With such an arrangement, with the fresh air intakes indicated in the figure and with the radiator as shown, we have an ideal sleeping room or, if the heater below is large and the room above small and warmly built, it may be a comfortable sitting room without the expense of additional heat.

Dwellings that are heated with hot air furnaces, if they are thus sufficiently warmed, are usually amply ventilated so long as the warm air is being forced in, unless the faulty arrangement has been adopted of returning the air from the heated rooms to the furnace to be revolved over and over again. Such a system is very bad and should never be used unless it be in faultily constructed houses where there is excessive air leakage through the walls or in windy weather when the temperature is excessively low. In steam-heated houses and in those heated with hot water by means of radiators distributed in the rooms to be heated the ventilation may be, and usually is, extremely deficient, much more so than with stove-heated rooms, for the reason that with these systems of heating there may be provision neither for air to enter nor leave the room, dependence being wholly upon leakage through the walls or upon the opening of windows and doors. In houses thus heated some means should be adopted for drawing the air out of the rooms at the floor level, even if nothing better than the plan suggested for the second floor in Fig. 39 at D. Fresh air intakes should also be provided and if possible these should be so placed that the air may be admitted at the

ceiling directly above the radiators, of course admitting the air from low down outside, as at A B, Fig. 39. When the fresh air intakes are thus located the currents of warm air rising from the radiators at once mingle with the fresh air entering, so that this is immediately and directly tempered. Of course very many variations will occur in making the necessary provisions for the ventilation of houses already built but enough has been said to permit such adaptations as may be called for.

Warming and Ventilation for New and Remodeled Houses.

As has been earlier said the real problem with which we have here to deal is, how nearly can we maintain the air of dwellings at the normal out of door fresh air purity with practicable economy. Accepting this statement as correct it follows that if pure air itself can be economically warmed and used as the medium for distributing heat through the house it by all means should be used, rather than water, as such, or in the form of steam. All but two of the twenty-eight years of our home-making have been spent in two eight-room houses, each with two stories with a cellar and a floored attic, full size. Both were of wood with walls of 2 by 4 studding covered with tongued and grooved fencing inside and out; papered and sided outside and lathed and plastered inside. The space between every pair of studding was ceiled at each of the three floors to prevent the circulation of air currents between rooms and attic due to leakage through walls and ceiling. The windows were all made with single sash but double glazed, except three in the second house, which were of plate glass. Each house has a single chimney beginning in the cellar, with three flues, the central one 12 by 12 inches, for the furnace and kitchen range, and two, one on each side, 8 by 12 inches for ventilation. Both houses are warmed with hot air, the whole lower floor except the front hall being maintained at 64° to 68° eighteen hours per day. Plants have been grown continuously in bay windows and on window brackets in both

houses and these have never been frosted. they have never been moved from the brackets to prevent freezing, the only precaution taken being to draw the curtains, and the furnace has never received attention nights after retiring, usually about 11 p. m. The first house was warmed more than fifteen years with a single cast-iron box stove, using four-foot wood, which was provided with a drum of sheet-iron and bricked in like a furnace. The second house is warmed with a No. 10 Economy furnace having a metal shield and using coal. The fuel bill for furnace and kitchen range in the first house ranged from $55 to $75 per annum. In the second house it has ranged from $64 in the earlier years, increasing with the price of coal, to $95.50 in 1908, using hard coal with some wood in the range, and gas coke at $6.75 per ton, and "buckwheat" coal at $6.50 per ton, burned together, in the furnace; "chestnut" at $9 per ton for the kitchen range. From this practical experience, covering a continuous quarter century of Wisconsin climate we feel justified in saying that in a warm, well-constructed house it is entirely practicable to economically warm an eight-room dwelling by distributing the heat with warm air, which at the same time serves the purpose of thorough ventilation. We think we are also justified in saying that if there is ever an investment that pays it is the little extra required to build a house for a cold climate warm, well and thoroughly ventilated, if your own family is to live in it. The saving in fuel alone is high interest on the extra money invested and you get the healthful conditions and comfort free. But we would not advise hot air warming for a house poorly constructed.

Rooms provided with fire-places may be well ventilated but seldom economically warmed. Steam and hot water are well adapted to heating all types of dwellings but the cost of installation and that of maintenance, excepting for fuel, is relatively high. Good ventilation may be provided with both hot water and steam but it is seldom that anything specific is done along this line and when proper ventilation is added the difference in cost of installation over warm-

ing with air becomes still greater. The perfect heating of a house with warm air is only made possible by first pro viding adequate ventilation because, before the warm air can enter a room the cold air must first escape. With both hot water and steam the house is most easily and cheaply warmed when there is the least ventilation.

We shall consider first the warm air method of heating and ventilation because, for homes of moderate cost, and especially in the country, distant from plumbing facilities, this method is more readily managed as well as more cheaply installed; and because such a dwelling must then be thoroughly ventilated if it is warmed. The first requirement is a warm, close construction and, everything considered, the cheapest thoroughly warm construction is a frame house sheated inside and out with low-grade hemlock, having the outer layer of sheating covered with the cheapest grade of roofing tin or a very light weight of galvanized iron carefully and closely nailed with edges slightly overlapping to thoroughly exclude the air. Walls so built may then be treated outside and in with any desired finish to suit the taste. The two thicknesses of 7/8-inch dry lumber forming air spaces between the studding, even if the boards are not matched or tongued and grooved, so long as the metal is used to thoroughly stop air circulation, will give a far warmer wall than building papers for the reason that the soft wood is, both because of its texture and its greater thickness, superior as an insulator to the building papers.

All spaces between studding should be thoroughly closed at the level of the three floors, which may be readily and best done by fitting in between the studding rough boards and then filling in with about six inches of a lean mortar, or concrete, which will thoroughly close the spaces and make the walls vermin-proof. Storm sash, fitting closely, on all but plate glass windows, should be provided. Farm houses should all have a cellar and floored attic the full size of the house. Both spaces are needed for both service and warmth and the extra cost, considering what is gained, should not lead to their omission. A good furnace of am

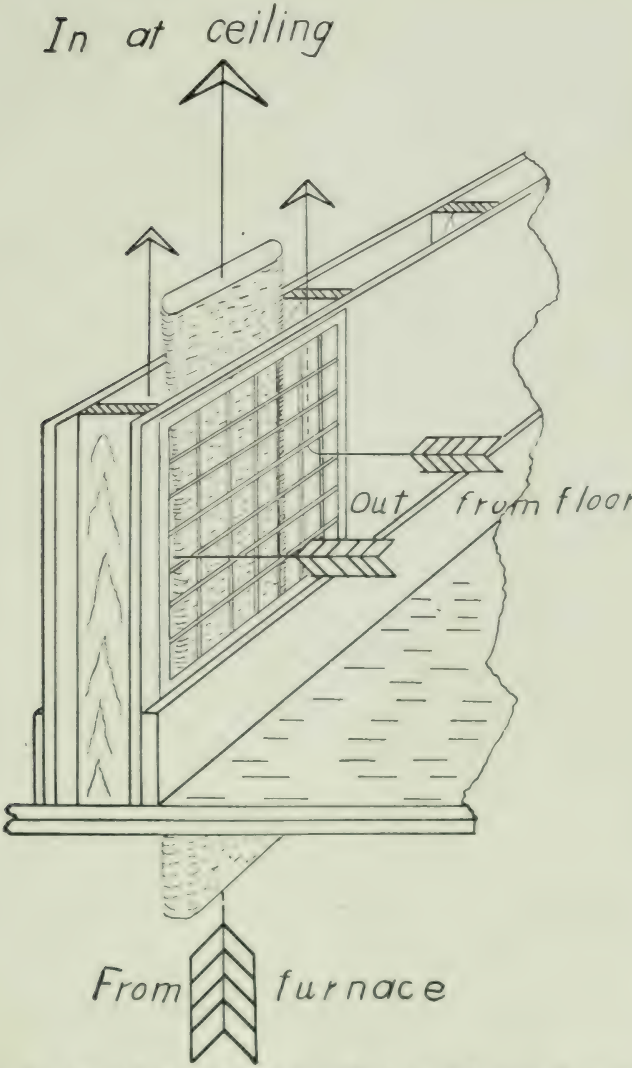


Fig. 40.—Method of introducing warmed air from furnace at the ceiling and of removing the fouled, exhausted and cooled air from the floor, both through the same space in the partition.

ple size, with conveniences for storing fuel, should occupy the basement, the location being chosen with special reference to the most direct connection between the furnace and the rooms to be heated. Both the warmed, fresh air and the fouled, depleted and cooled air may be most advantageously conveyed through the partitions in the manner represented in Fig. 40, the warm air, as represented by the long arrow, passing from the furnace through the flue and entering the room at the level of the ceiling while a corresponding volume is forced out from the floor level as shown by the other two arrows.

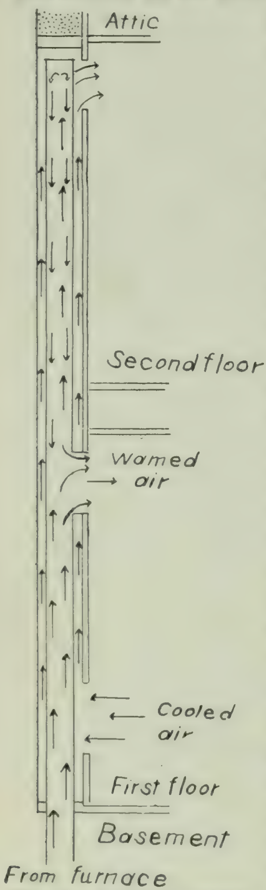


Fig. 41.—Method of ventilating a lower room into an upper one.

In most houses constructed in the manner described it will only be necessary for the ventilating flues to extend into the attic ventilating all rooms into this space which then makes an excellent clothes drying room for blustering and stormy weather. The air may pass either directly into the attic from each room, or it may be passed into the room above, thus warming it indirectly in the manner represented in Fig. 41. In this case the warmed air flue extends to the level of the ceiling of the room on the second floor where it is closed, the air leaving by an opening at the ceiling of the first floor. With this arrangement forced ventilation for the first floor is provided. The flue being all the time filled with warm air heats the surrounding air in the same space thus giving a column 18 or 20 feet long to aid in producing a draft out of the lower room. The

upper room may thus be largely or wholly warmed without extra heat. To secure this result the space between the pair of studding is made sufficiently large, as seen in Fig. 40, to contain the warmed air flue and provide ample room to act as a ventilator. Before lathing the partition the hot air flue is installed and the space closed by covering with roofing tin or a light weight of galvanized iron. This makes a safe arrangement and permits the hot air flue to have a single wall. At the same time a tight-walled ventilating shaft is provided for the lower room. With this arrangement it is necessary to provide ventilation for the upper room. This may be done by opening into the space between another pair of studding letting it discharge into the attic. If more heat is desired for the upper room a plan similar to that represented in Fig. 42 may be adopted, which is an extension of the principle of Fig. 41.

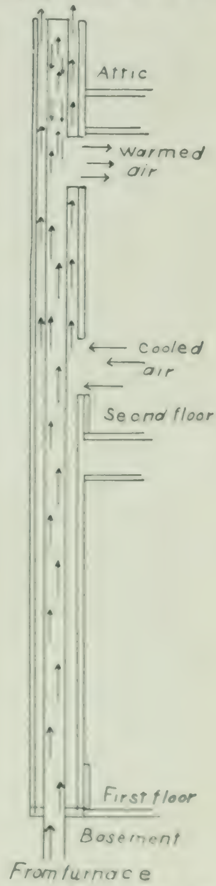


Fig. 42—Method of heating upper room and ventilating into the attic.

If only direct heating and direct ventilation are desired then the method will be essentially the same as in Fig. 41, the hot air flue extending to the attic floor in either case so as to secure the maximum forcing effect. The chief objection to the methods of warming and ventilating the house as has been described is the comparatively small motive power for ventilation at times when there is no fire in the furnace. It is true, however, that at such times the house is more or less thrown open through doors and windows.

Another method for direct heating and ventilation is represented in Fig. 43 where there is a central chimney of

brick, with flue lining, surrounded with a ventilating shaft made of galvanized iron nailed directly to the studding before lathing. In this diagram four rooms directly adjoining the chimney are represented as being ventilated at one floor level. Distant rooms on the same floor may be connected with the same flue by leading a fouled air duct under the floor cut into the ends of the joists under the partition, or in the space between two joists if they extend in the right direction. If it is so desired these ventilators may be finished in imitation of fire places.

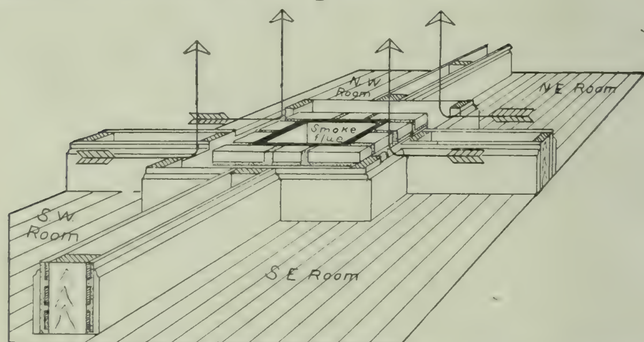


Fig. 43.—Ventilating flue of galvanized iron surrounding the chimney and utilizing the warmth of the smoke flue to force the draft in the ventilator. A flue lining is used inside the brick.

If so desired the ventilating flue may begin at the second floor or even at the attic floor when it is desired to warm the upper rooms with the exhaust air from the lower ones. Such a plan, however, cannot derive as much advantage from the warmth of the chimney.

If it is desired to heat with either steam or with hot water some system of ventilation should by all means be installed at the same time and this can be done without difficulty and without greatly increasing the cost as will be readily seen from a study of Fig. 44. In this type of house warming the radiators should be placed under the fresh air intakes where the warmed air will rise where the cold air enters and falls.

When fresh air intakes are provided for each room to be occupied and ventilators are provided in some one of the

ways already described and illustrated ideally sanitary homes will be provided so far as fresh air is concerned. The air may exhaust through a fireplace, through a shaft

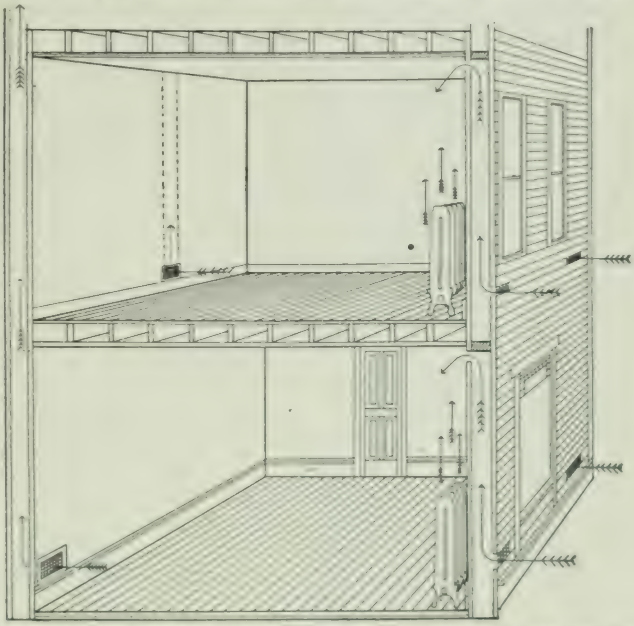
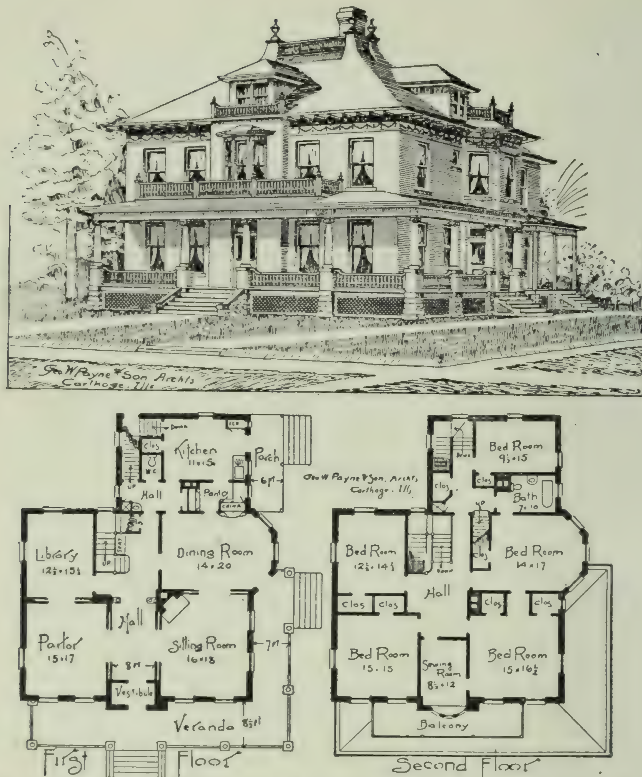


Fig. 44.—Ventilation of a house warmed with steam or with hot water.

built about the chimney as illustrated in Fig. 43, or by means of flues placed in the partitions and exhausting into the attic or directly through the roof.

In the next illustration is shown a type of house which is extremely well designed to meet the needs and comforts of country homes. It may be made larger or smaller; the verandas and decorations may be altered to suit the taste or expense; for a smaller house the kitchen may be omitted and one of the other rooms adapted to this purpose. It is a type which lends itself well to economy of construction, to economy of heating, and it may be well ventilated by any system of heating if proper attention is given to the matter when laying out its construction.



Figs. 45 and 46.—Elevation and floor-plan of house readily warmed and ventilated.

HEATING AND VENTILATION OF RURAL SCHOOL-HOUSES AND CHURCHES.

Now that concrete construction has been so far perfected and cheapened it appears to the writer that we are in position to build all new country school-houses and churches in a manner which will permit of their being both ideally warmed and thoroughly ventilated. To have conditions right both school and church should have thoroughly warm floors and they should have a moderately warm atmosphere

which is being rapidly and continuously changed. To secure these ends it is necessary to remove the heater to a basement and then permit none of the air which comes in contact with it to become a part of the air supply. This,

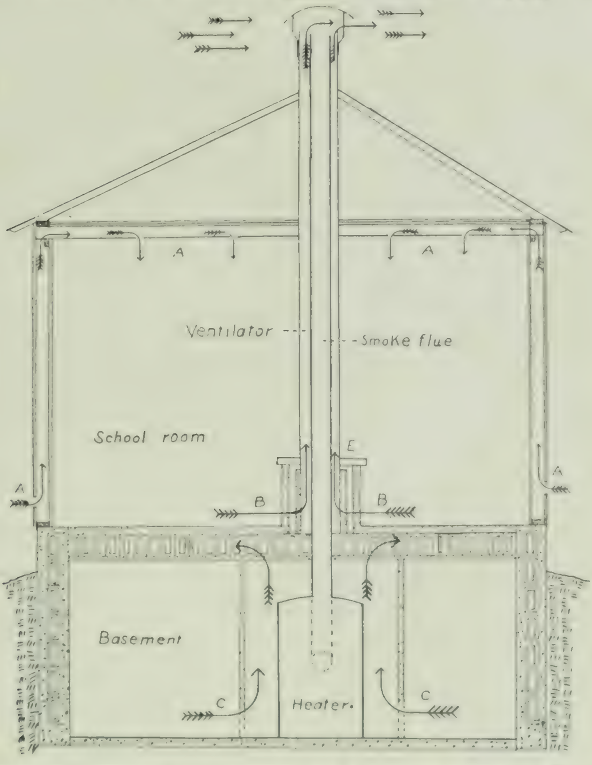


Fig. 47.—Warming and ventilation for a country school or church.

in our judgment, may be readily done and more economically than warming with poor ventilation is now accomplished.

Describing first a country school-house built along these lines, as represented in Fig. 47, there is constructed a monolithic concrete basement, including the first floor, using in the walls, for warmth, hollow building tile bedded in the concrete mass. These tile are cheaper than the concrete

and they offer the most expeditious way of securing a hollow wall. On the walls is constructed a reinforced concrete ceiling and floor, the ceiling built first and covered closely with a layer of hollow tile carefully laid in series so as to form continuous air ducts through which to circulate heated air for the purpose of warming the floor and through it, as a radiator, the room above. A cement floor is then laid over the tile.

Across the center of the floor-ceiling the tile would be omitted over a strip three or more feet wide forming a broad duct into which the heater casing communicates so as to flood all of the tile with hot air and thus warm the floor. At the two ends of the building a similar but narrower duct is formed which permits the heated air to escape and return to the heater, thus providing means for the continuous circulation of the same mass of air on the principle of the circulation of water or steam. The heater room should have tight walls except near the floor so as to confine a column of heated air, this being the motive power for maintaining the circulation. The air then enters the heater chamber at C, Fig. 47, passing to the ceiling to be distributed through the various channels and is again returned to repeat the circuit indefinitely.

The room to be warmed and ventilated above is closely constructed and finished with a ceiling provided with openings AA through which the air may enter from the outside as indicated by the arrows AA AA; the air rising between the studding and along the spaces formed by the joists. The floor above these joists must be very tight and warm. The air everywhere in contact with the floor is warmed and forced to circulate as it would be if steam or hot water radiators were used.

The chimney is best made of suitable size wrought iron pipe or boiler tubing or else of a heavy weight of sheet iron riveted and this should occupy the center of the ventilating shaft, which is best made of galvanized sheet iron. With this construction, the air entering the shaft from the room at BB is forced out by the waste heat of the smoke flue; and

fresh air directly from outside is thereby continuously drawn in through the intakes AA. In the illustration E suggests a way in which a hot air radiator may be installed furnishing a convenience for hand warming if desired; here warm air simply circulates from and to the furnace and does not escape into the school room. It may be made in cement.

The great advantage of heating from the basement in some manner is that it insures a thoroughly warm floor. When the feet are adequately and continuously warm a lower surrounding air temperature is admissible and this makes it quite certain that a larger air circulation will be maintained which is the important point in every school room. It follows, therefore, that even if the heater is not placed in the basement there should be a good cellar under the whole floor with warm walls and deep enough not to freeze and to serve as a store room for kindling and fuel and to help keep the floor more comfortable to the feet. If a cellar will not be built then a damp-proof cement floor laid directly on the ground, which may be covered with a layer of boards or linoleum if desired, is far warmer and more sanitary as well as enduring, than many of those now in use.

If the heater is in the school room, its proper place is central on the floor but near the entrance. It should be surrounded on three sides with a metal shield, open toward the door, to cut off direct radiation from the children. The smoke flue should rise straight out through the roof, and it should be surrounded by the ventilating flue as represented in Fig. 48, drawing out the fouled air at the floor level and from behind the screen at A. The fresh air should be introduced through the ceiling rising through the walls from low down outside, Fig. 47, discharging largely in the front of the room and over the heater where it may mingle directly with the warmest air; or it may be taken directly down through the roof in the manner shown at BB where the duct is provided with a revolving cowl at the top, to utilize fully the wind pressure, and with an air trap at the lower end to prevent the escape of warm air. In still an-

other way the air may be let in beneath the floor and directly up under the stove and inside the jacket. The advantage of the method of taking fresh air represented in Fig. 48 is

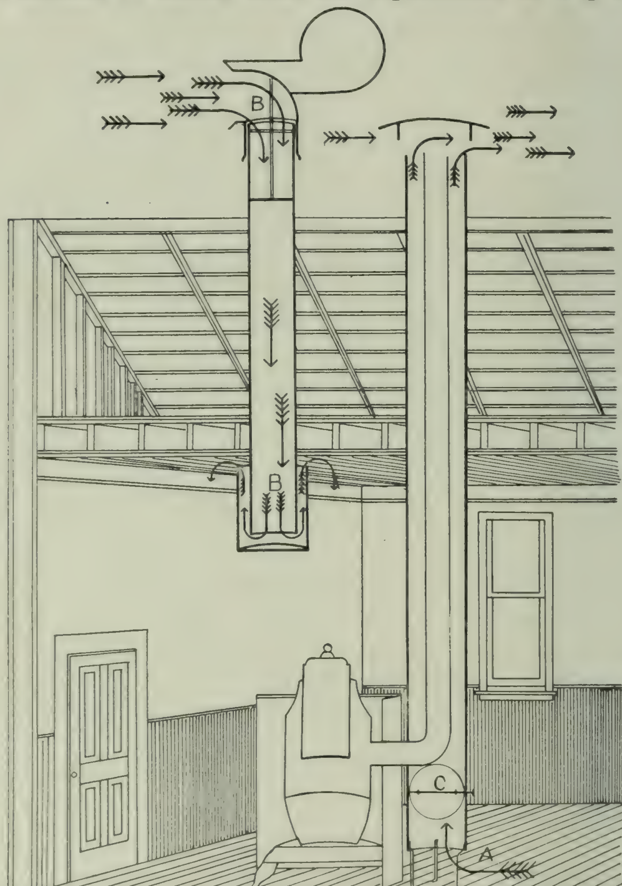


Fig. 48.—Ventilation of school room which must contain the heater.

that when there is little or no fire in the heater to force a draft, the combined effect of wind pressure and wind suction may be utilized. A damper in the ventilating flue at C permits the amount of air moving to be controlled at any time.

Ventilation of Dairy Stables.

In the details of stable ventilation there must be almost endless variation to meet individual conditions. Notwithstanding this, the principles governing construction are few and have already been stated in general terms. Because the motive power usually available in stable ventilation is both small and variable in intensity it is of the highest importance that strict attention be given to all essential details of construction necessary to adequate efficiency.

The one detail of paramount importance in every system of stable ventilation is the outtake flue. It is, in function, nothing more than a chimney; it should be nothing less than one of the best type, barring the single feature that it need not be fire-proof. Whatever is counted essential in a good chimney must be held even more essential to a good stable ventilating flue; and whatever would be ruled out of the construction of a good chimney must be more scrupulously excluded here, and for the simple reason that the motive power at best is small when compared with that available in most good chimneys. The walls of the outtake should be so made as to be and to remain permanently air-tight except where openings are provided. This feature is essential in order that only air from the space to be ventilated shall contribute to the current passing through. In practice many outtakes have been constructed so openly, above the stable to be served, that their efficiency is thereby greatly impaired. Next in importance is an ample cross-section, uniformly so throughout its length. If the outtake is constricted at any point the smallest section determines its capacity. Reducing the diameter of a cylindrical flue one-half makes the pressure necessary to force a given volume of air through nearly four-fold, while doubling the diameter permits one-fourth the pressure to do the work. The outtake which is circular in cross-section or square is to be preferred to one long and narrow, because the wall surface for cooling the air and for friction is relatively materially less

and this means less loss of pressure and hence greater flow when the motive power is small. The oblong section may be chosen if conveniences require it, but then the area should be made relatively greater. The motive power for ventilation due to temperature differences increases with the hight, and the suctional effect of the wind does also, but the loss of

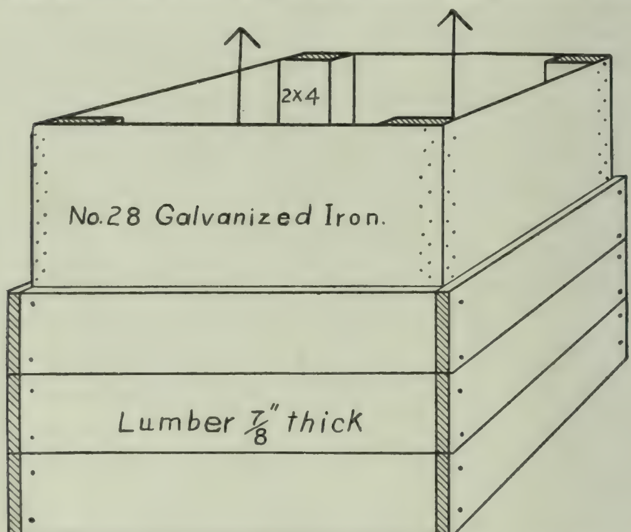


Fig. 49.—Showing manner of constructing outtake flue, using 2x4's for corners and galvanized iron for walls, covered with wood if greater warmth is important.

power due to friction increases with the length and with bends. The outtake should, therefore, be free from angles wherever practicable.

Galvanized iron is the best available material with which to construct the walls of outtake flues, and they are most simply made in the manner shown in Fig. 49. The sheets of metal may be obtained in widths from 24″ to 36″ and in lengths of 8′ or 10′. The metal should be nailed closely as represented in the upper part of the figure, using small galvanized wire nails to avoid rusting out. If the flue is in an exposed situation it may be covered with wood, as shown

in the lower part of the cut, to lessen the cooling of the air during its passage, or the flue may be made larger to compensate for loss of power through loss of heat. Where the ends of sheets meet pieces should be cut in between the uprights into which to closely nail the ends, overlapping about an inch.

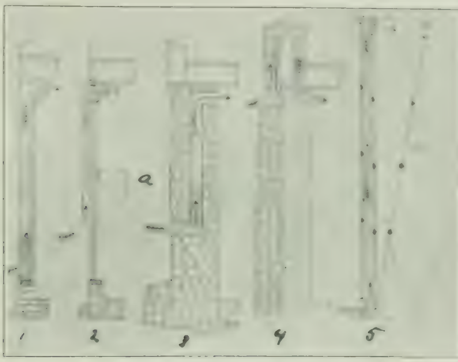


Fig. 50.—Several types of intakes. 1, utilizes space between studding; 2, made of galvanized iron shaped as at a; 3, constructed in masonry wall; 4, for basement stable already built; 5, utilizing space between double windows.

At present prices the metal is cheaper than paper for the reason that only a heavy grade of acid and water proof variety is permissible and this can only safely be used between two layers of tongued and grooved boards. Without this precaution the paper will warp and tear itself loose and it is liable in any case to disintegrate in time, leaving leaks between the boards.

The construction of the intakes is not a matter of such critical importance. Almost any sort of flue will answer. They should be numerous, well distributed on all sides of the stable if practicable, and, in order that they may trap the escape of the warm air of the stable, the outside opening should be three or more feet below the inlet. Their aggregate cross-section should equal if not exceed that of the out-

takes, unless the stable has an open construction, for the reason that air can continuously leave the stable no faster than it can enter. Small intakes distributed at intervals of about 12 feet are to be preferred to large ones, there being then a better commingling of the cold with the warm air and less danger of cold drafts.

Ventilation of Dairy Stables.

In January, 1889, we received a request to design a barn for a dairy farm which would accommodate 80 cows and 10 horses and which would permit of driving behind the cows in cleaning and in front in feeding. A silo, granary and storage space for roughage sufficient for all the stock were desired and it was specified that all should be under one roof, every thing conveniently accessible and not relatively expensive. The barn was built during the summer of the same year on the farm of Mr. C. E. King, Whitewater, Wis., to accommodate 98 cows, and was the first structure to contain the ventilation system for stables here described. In describing the barn for the Seventh Annual Report of the Wis. Agr. Exp. Station we said: Whatever conveniences a barn may contain these should in no way interfere with the best performance of the animals housed. It should be so built that the heat given off by the animals housed shall be sufficient to maintain the best stable temperature and at the same time admit of ample ventilation. It should admit the necessary amount of light to all the animals and be so constructed as to reduce care-taking to a minimum.

The barn as erected is represented in Fig. 51 and was of the cylindrical type, 92 feet in diameter, two stories, and costing at that time, with the average price of lumber $15 per thousand, a little less than $2,400, not including the board of the carpenters. The manner in which the ventilation was secured is shown in Fig. 52 where the 32 spaces between the studding in the walls of the silo, 34 feet high,

are utilized as outtakes, having an aggregate cross-section of 35 square feet. Here, not only are these outtakes cen-

Fig. 51.—First barn in which the King system of ventilation was installed, in 1889.

trally located in the warmest portion of the barn with the cows grouped about them, but the warmth of the inner walls of the flues, maintained by the heating of the silage, is

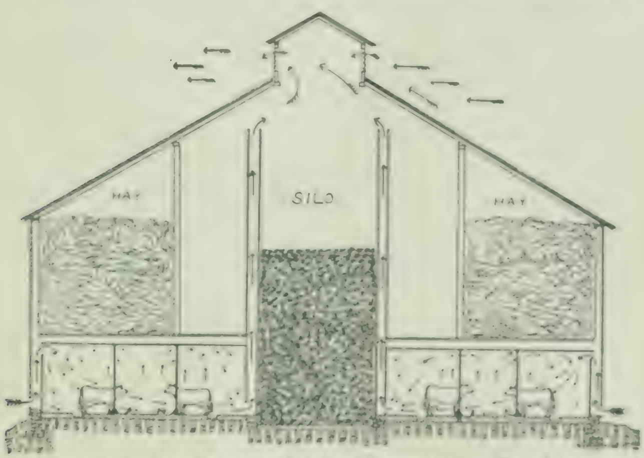


Fig. 52.—Showing cows arranged in two rows centrally about outtakes in the entire circumference of the silo, and with intakes for fresh air between every fourth pair of studding in the wall.

utilized as a constant motive power to force the air movement through them. Intakes for fresh air are provided between every fourth pair of studding around the entire circumference of the barn. By this arrangement there is se-

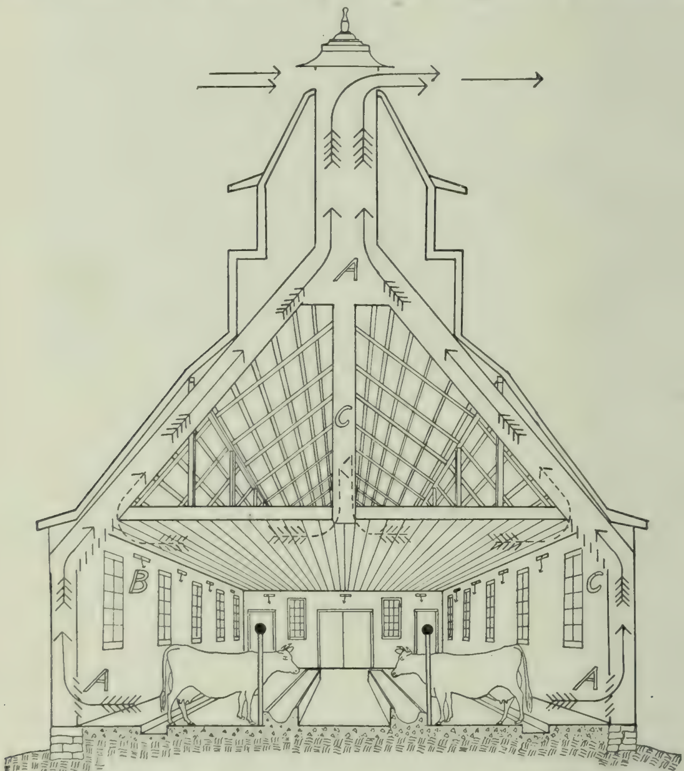


Fig. 53.—Showing the inverted-Y type of outtake used in the dairy barn at Wisconsin Agr. Exp. Station. A A A is the outtake flue; C. C. provisions for cooling stable and reinforcing the draft. Intakes for fresh air at ceiling represented at B.

cured a continuous flow of fresh air in at the ceiling of the stable uniformly past every animal while the fouled and impoverished air is at the same time being drawn off at the floor level. A thoroughly adequate and continuous air movement through the stable is thus secured without extra cost of construction.

The ventilation system installed in the dairy barn of the Wisconsin Agr. Exp. Station, which accommodates 38 cows, is represented in Fig. 53. In this case the outtake is a single central shaft in the shape of an inverted Y as seen

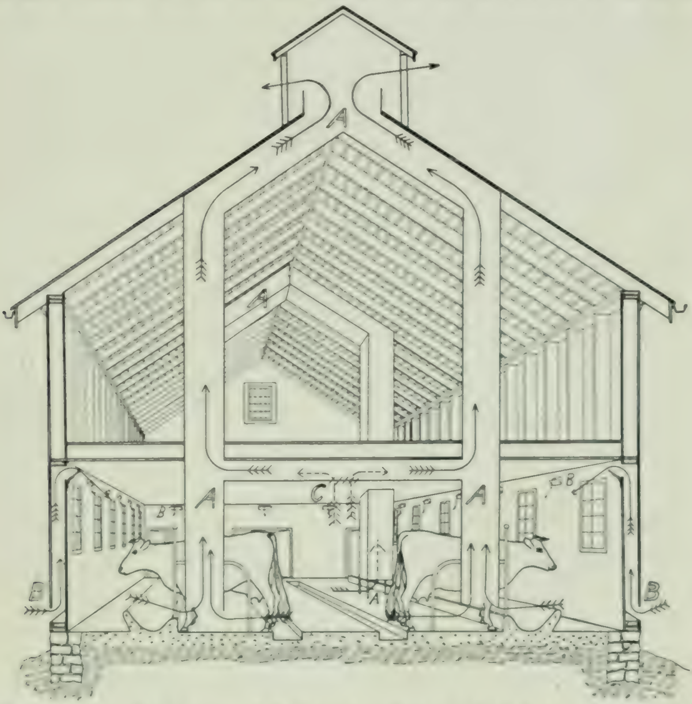


Fig. 54.—Showing a pair of U-shaped outtakes adapted to stables for 60 takes; C ceiling register in a cross-arm joining the two sides of the to 80 cows. A A A A A are the two outtakes; B B B B are the in-outtake.

at AAA with a small outtake, C, opening at the ceiling for use in conjunction with the other registers C to be opened only during still weather when the stable is too warm or the movement of air too slow. The fresh air intakes, shown at B by the series of small rectangles with arrows, are 24 in number, each 4x12 inches, the air entering just above the sill outside, and rising between as many pairs of studding.

A more effective arrangement for the outtakes is repre-

sented in Fig. 54, which shows two U-shaped flues rising from just behind the manger between two cows in a stable adapted to 60 or 80 cows, seen at AAAAA, with a ceiling register at C for use when the stable is too warm and to reinforce the draft when needful. For 20 cows and for 40,

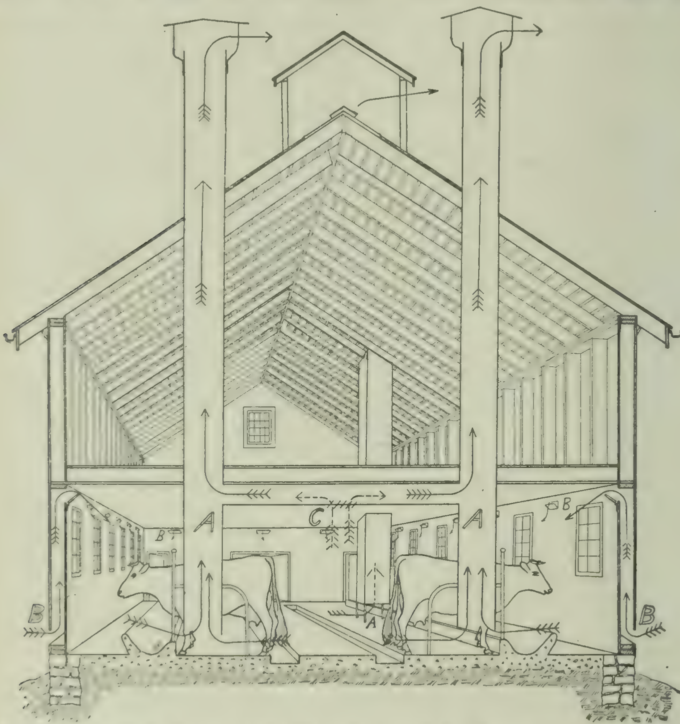


Fig. 55.—Showing single straight-away outtakes which avoid all angles and render possible the strongest draft.

one of these U-shaped outtakes would answer, located near the center of the stable.

A still better and perhaps the best practicable arrangement of the outtakes is represented in Fig. 55 where each shaft is straight and rises directly through the roof and above the level of the ridge to be fully out of the zone of air currents which tend to produce down drafts.

In the next illustration the outtakes are straight but oc-

cupy positions against the outer walls. Here they are less in the way but they must be projected farther above the roof and are more unsightly as well as being where the animal heat is less efficient. In barns already built, and especially if the animals are few and a cupola exists, this plan may be safely adopted with the modification that the outtakes may be carried up to the roof inside and allowed to stop there or be turned toward or to the cupola.

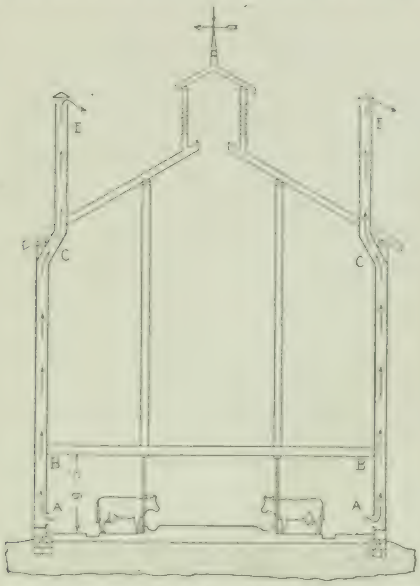


Fig. 56.—Showing straight-away outtakes placed against the wall.

In Fig. 57 the arrangement differs from that of Fig. 55 in having the lower ends of the outtakes against the outer wall, thus removing them from between the cows. There is another partial advantage to offset the loss due to greater length and angles. If the under face of the outtake along the ceiling is made of galvanized iron the warmest air of the stable will come continually against it and thus keep it warm to assist in forcing the draft.

Where there is a lean-to stable, as represented in Fig. 58,

the outtake may be constructed inside the main barn and terminated as represented, or it may be carried under the roof to the cupola or to the ridge. If only a few animals are

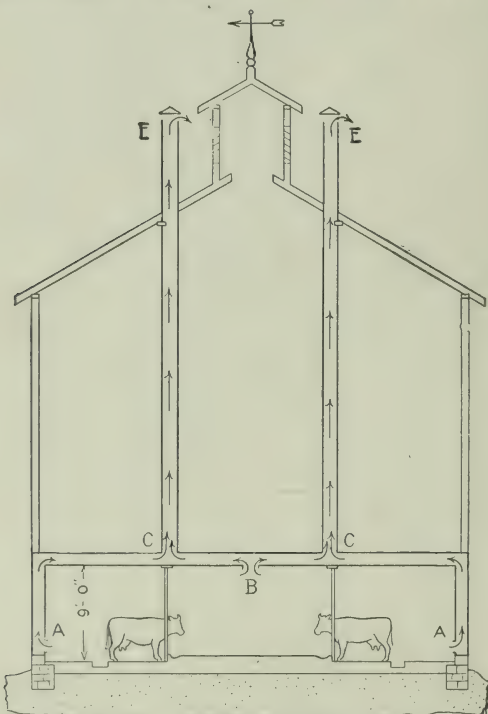


Fig. 57.—Showing manner of placing only the lower ends of the outtakes against the outer walls.

to be supplied the flue may be made relatively large in cross-section and terminated in the main barn just under the roof.

In barns already built without special provision for ventilation it may be possible to utilize one or more of the hay chutes, if they exist, by extending them to the floor, as suggested in Fig. 59, to prevent the loss of air at the ceiling. Lifting or swinging doors may then be provided to be always closed except when the hay is being put down.

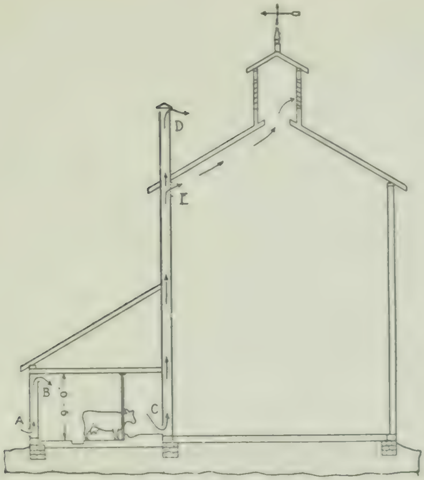


Fig. 58.—Showing method of ventilating a lean-to.

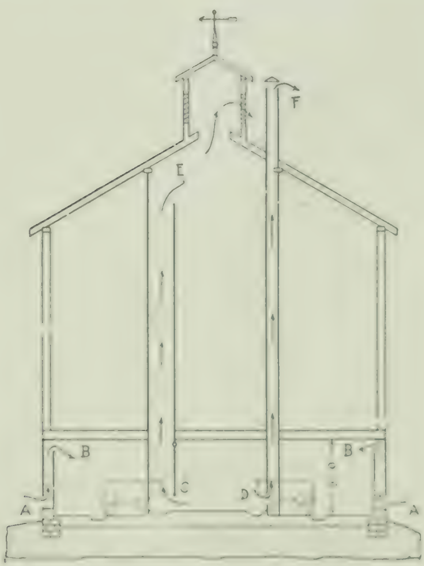


Fig. 59.—Showing method of utilizing a hay chute as an outtake.

The provisions for taking fresh air into the stable wherever the walls are hollow and rise four or more feet above the ground have been sufficiently illustrated in preceding figures. In stables having solid masonry walls already constructed the fresh air intakes may be made in the manner illustrated in Fig. 60 where an intake flue is shown

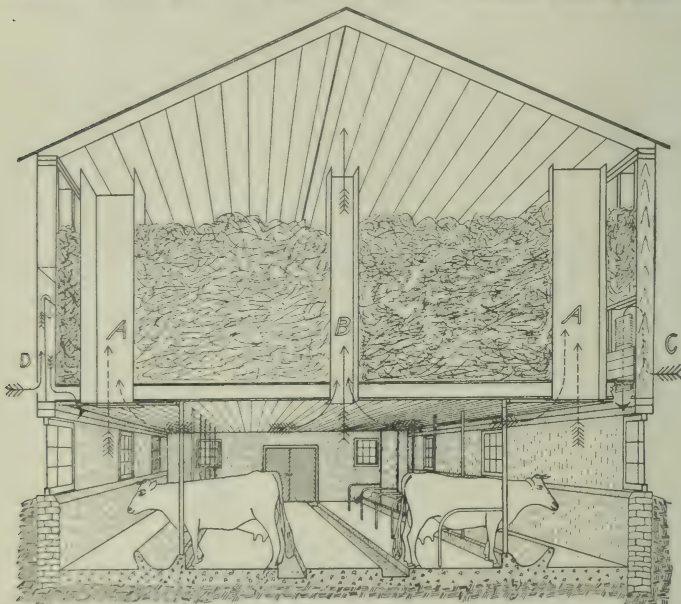


Fig. 60.—Showing two methods of admitting fresh air to basement stable C and D. The two hay chutes and the small ceiling ventilator are not intended to illustrate proper outtakes.

at C, the large arrow indicating the course of the air current in entering the stable. Here the space between a pair of studding is closed off at a hight of 4 or 5 feet and in it is inserted a light tin 10 inch pipe flattened to 4 inches and inserted in an opening through the stable ceiling. The space is then ceiled up and a 4-inch opening cut in the outside wall about the length of the long diameter of the tin flue, for the entrance of air. The number and distribution of these should be the same as in the case of the ordinary intakes.

On the left side of the figure is illustrated another way of providing intakes. The space between a pair of studding is closed at the proper hight and all but the upper portion is divided by a partition in the manner shown. This partition is most simply formed out of a piece of light galvanized iron of proper width and hight having the bottom and the two sides turned at a right angle for the purpose of nailing it in place. Where the siding of the barn is nailed in place vertically intakes may be formed by using two strips of galvanized iron formed up as just described, nailing them on opposite sides, each with the open end down, thus forming two arms, one outside and the other inside extending through the stable ceiling with the two connecting at the top through an opening cut in the siding.

Where masonry walls are being constructed for stables the intakes are readily formed in the building of them by placing in the wall a proper form. The forms may be hollow building tile, drain tile or shapes in wood providing the desired capacity, simply set in the place desired and the wall built about them.

From the statements made relating to the principles of ventilation, in the preceding section, it follows that the area of cross-section of both the outtakes and the intakes must depend in an important degree upon the hight of the outtake. If the ventilating shaft is low then it must have a sufficiently larger cross-section to compensate for the less velocity of air current in the flue which is always associated with short shafts. In my earlier writing it was stated that a ventilating flue 2x2 feet through which the air moved at the rate of 295 feet per minute, or a little more than 3 miles per hour, gave sufficient air for 20 dairy cows. This statement does not mean that any flue 2x2 feet will carry out of the stable sufficient air for 20 cows. Such a flue can do so only when the velocity of the air current is rather more than 3 miles per hour.

Let us refer back to the table on page 56. Take the column for the 20 foot outtake. These cubic feet of flow per hour for the one-foot flue also mean velocity in feet per

hour, and hence if we divide these numbers by 60 the result will be the velocity in feet per minute. Doing this we get the round numbers 97, 307, 434, 532, and 615 feet respectively for stables which are warm enough so that the air in the flue is 1°, 10°, 20°, 30°, and 40° warmer than the air outside. But these are theoretical velocities, no allowance having been made for friction and other resistance to flow. It is quite likely that the actual velocities might not be more than one-half those computed. If so then only the last three differences in temperature between the air in the outtake and that out doors, namely 20°, 30°, and 40° will permit a 20-foot flue to supply air enough for 20 cows when its size is 2x2 feet. As the cows must breathe all of the time and as there are times when there is little or no effective wind, difference in temperature must chiefly determine the dimensions of the outtake and intakes and the two should be approximately equal in area of cross-section. The difference between the stable temperature and that of the outside air as given on page 66 ranges from 24° to 61° and averages 39°. The temperature in the ventilating flue will certainly average materially below that in the stable and as it is the temperature in the ventilating flue, compared with that outside, which determines the draft, the mean effective difference of temperature will be found to average materially less than 39° and probably nearer 20° than 30°. With a temperature difference of 25° a 30-foot shaft will give just about the required flow. The conclusion which should govern practice, therefore, is: *Outtakes and intakes for horses and cows should provide not less than 30 square inches per head when the outtake has a hight of 30 feet; if the outtake is shorter the area should be greater, if higher it may be less.* A 20-foot outtake would require about 36 square inches per head instead of 30.

Ventilation for Swine and Sheep.

In the construction of quarters for both swine and sheep it has been the practice to build lower ceilings and quite

generally lower stables for them than for horses and cattle. Both kinds of animals being small and given the freedom of the stable in common, over-crowding has been more frequent and this practice, coupled with the lower ceilings, has resulted in their suffering from the effects of insufficient ventilation oftener than horses and than cattle, except in later years when the number of individuals in a herd has been greatly increased. Sheep are extremely well protected from cold by their heavy fleece of wool; so too, are swine of cold climates, when in good condition, by the thick layer of fat interposed between the skin and the more vital parts, serving the double purpose of nourishment stored against need and a weather garment. We doubt very much, however, that these protections mean these animals are, necessarily, best maintained in severe climates with little or no shelter. Indeed, in the admitted absence of exact knowledge to the contrary, there are good reasons for the belief that if both sheep and swine could be wintered under temperature conditions varying but little from 35° F., except when they are given freedom for needed exercise, better results would follow than with simple protection from winter storms, provided ample ventilation always went with the warmer housing. The thorough insulation nature has provided for the bodies of these animals makes it necessary that a larger percent of the heat produced in the body must be wasted through breathing and, for this reason, it may be expected that they will thrive better in a somewhat colder air than will cattle, but only enough colder to remove the animal heat through the relatively smaller surface.

For the reasons stated, if sheep and swine are housed, relatively larger air movement should be continuously maintained through the stable, and for the additional one that they breathe more air per hour in proportion to their weight. Then because the stables are lower, the outtakes shorter, and the difference in temperature less and the wind velocities as well, it is necessary to provide relatively larger outtakes and intakes. If the minimum movement of air through a 1-foot outtake 20 feet high is taken at one half the

value in the table, page 56, where the temperature difference between the air in the flue and that outside is 10°, it will be 9,204 cubic feet per hour; with this rate of flow and on the basis of 1,392 cu. ft. and 917 cu. ft. of fresh air per hour and per head for swine and sheep respectively there should be provided an area of 22 sq. in. per head for swine and 15 sq. in. for sheep for both outtake and intake flues. If the outtake flue has a hight of only 15 feet then the number of square inches should be not less than 26 for swine and 17 square inches for sheep per head for outtake and intake flues. For 16 swine provided for, as represented in the floor plan,

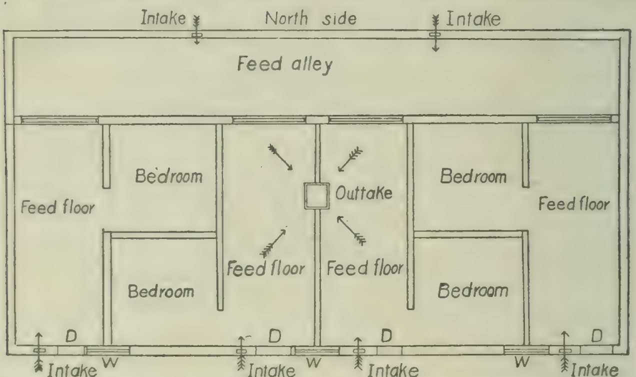


Fig. 61.—Showing floor-plan and ventilation of a piggery. The outtake extends to within 12 inches of the floor and admits air on four sides.

Fig. 61, the outtake would need to be not less than 18x18 inches inside with a hight of 20 feet; and 20x20 inches if the hight is 15 feet. With the outtake located centrally and consisting of a single flue it has the maximum efficiency and a minimum cost.

In the next illustration, Fig. 62, is represented both floor plan and elevation of a sheep stable with a ventilation system installed which is both incomplete and inadequate. Observe that the outtakes all terminate below the level of the ridge of the roof, which both lessens their efficiency and renders them liable to reverse draft when the wind is in one direction. In the 80 feet covered by the 10 pens there are

provided as many outtakes, each 6x6 inches and less than 15 feet high. The space ventilated should accommodate at least 50 sheep; each of the 10 outtakes should then have had a cross-section of 85 instead of 36 sq. in. as they do possess. A single central outtake 28x28 inches, rising directly

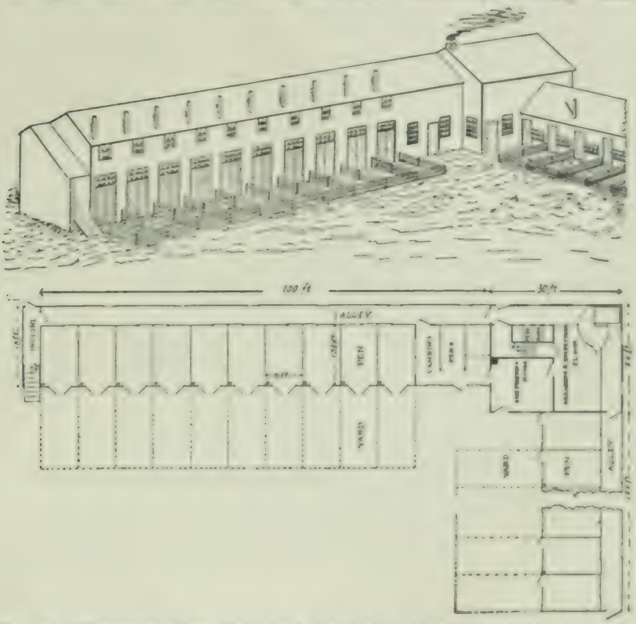


Fig. 62.—Showing floor plan and elevation of sheep stable in which the outtakes are too short, too small and more numerous than needed; and where no intakes have been provided, as should have been.

through the ridge of the roof 20 feet above the stable floor, would give much more efficient ventilation. Two main flues 18x21 inches placed one-third the distance from either end would be rather better than a single central flue. Intakes discharging air in at the ceiling and drawing it from near the ground level outside should be distributed along each side with openings 3x12 inches, 20 of them, 10 on a side.

Ventilation of Poultry Houses.

So soon as an attempt is made to house any considerable number of hens in warm winter quarters, not made so with

the aid of artificial heat, provision for ventilation becomes imperative if healthful conditions are desired. It has been stated that a hen breathes about 1.2 cubic feet of air per hour. In one hour 50 hens would respire 60 cubic feet, highly charge it with moisture and raise its temperature to near 97°. This is 2.68 per cent of the volume of air contained in a room 20x16x7 feet, the space commonly allotted to this number of birds. There is heat enough in 60 cubic feet of air at 97° to represent

$$97 \times 60 = 5{,}820 \text{ cu. ft. raised } 1°.$$

The total air in the room in question is 2,240 cu. ft. Suppose this has a temperature of 20°; this is heat enough to represent, taking out the 60 cu. ft. the hens have breathed,

$$2{,}180 \times 20 = 43{,}600 \text{ cu. ft. raised } 1°.$$

If we now add these products we have

$$43{,}600 + 5{,}820 = 49{,}420 \text{ cu. ft. raised } 1°.$$

Dividing this total by the total amount of air in the room we get

$$49{,}420 \div 2{,}240 = 22°.$$

That is to say the 50 hens, by breathing 60 cubic feet of air out of the 2,240 and warming it to 97°, letting it again mix with the balance in the room, have raised the general temperature from 20° to 22°. It is clear, from these figures that 50 hens are unable to warm through many degrees any large volume of air.

Prof. Gowell, of the Maine Agricultural Experiment Station, recognizing this fact in a practical way, has designed for poultry houses a sleeping chamber, by enclosing the roosts in a floored space just under the ceiling and providing the entire front side of this chamber with doors of rather light canvass, hinged at the ceiling so that on cold nights these may be closed down for warmth. The size of the sleeping chamber recommended by Gowell is less than 4x4x20 feet and the only ventilation provided is through the canvass doors. It is clear that the smaller volume of air enclosed in the sleeping chamber would be maintained at a higher temperature unless the air was changed in it at a

more rapid rate. Taking the capacity of the chamber at 320 cubic feet and supposing that its air is changed once per hour and replaced with that at 20°, breathing alone, not allowing for loss, should maintain a temperature 14° higher or 34°, the air of the chamber having one-seventh the volume of the room considered above. But if the air in the chamber is changed but once per hour it would contain 18.75 per cent of air once breathed, instead of 3.3 per cent, the standard we have assumed as possibly permissible for

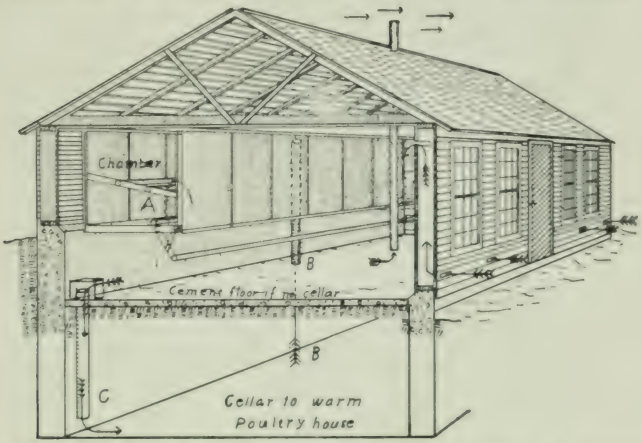


Fig. 63.—Showing method of ventilating a poultry house. A is sleeping chamber without floor; B is flue to admit warmed air to sleeping chamber from cellar if one is provided; C is duct to admit air from floor of house to cellar to be warmed. If no warming cellar is provided the floor should be cemented.

cows. We doubt if under the conditions recommended by Gowell the air will be changed oftener than once or twice per hour and such a rate does not appear to be sufficient.

In view of the considerations here presented we have designed the poultry house represented in Fig. 63. As shown, it is 16x20x7 feet and intended for 50 hens. To guard against low temperature a cellar is suggested under the whole floor with provision for air to circulate as shown in the drawing, thus utilizing the ground heat for warming. If a location can be chosen which permits all but the south

front to be largely in the bank and a cement floor is provided to conduct the heat of the subsoil into the house through the general floor, this will do much for warmth. Indeed, with four long windows on the south, we do not hesitate to recommend, for severe climates, placing the chicken house in a bank with the floor cemented and 18 to 24 inches below the ground level in front. Such a house, because it can be more thoroughly ventilated, will be less damp and more wholesome.

For houses wholly above ground, the walls must be closely and warmly constructed. A very warm wall may be made with 2x8's set 3 feet apart, covered with drop siding outside and matched fencing inside or, what would be best, a light weight of galvanized iron nailed closely and vertically to the studding, filling the spaces between the studding compactly with dry fibrous peat. The ceiling likewise should be similarly built so that no air may escape through it. A very warm ceiling could be made by tightly packing the space above very closely with marsh hay, represented in Fig. 63. A very warm poultry house can be made by using 2x8 studding, covered with drop siding outside and only with a light weight of galvanized iron inside, with the space between the studding closely packed with fine marsh hay and treating the ceiling as already described. The closely packed hay makes one of the best of nonconductors, while the metal makes the walls and ceiling both air-tight and sanitary in every way.

It will be clear from statements made on page 63 that where the ventilating flue for poultry houses may rise 16 feet above the floor the cross-section of both outtakes and intakes should provide some 4 square inches per bird, or at the rate of 200 square inches for each 50 hens or their equivalent.

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THE SOIL

By F. H. KING

Professor of Agricultural Physics in the University of Wisconsin. 1888-1901; Chief of the Division of Soil Management. U. S. Department of Agriculture, 1901-1904.

Author of "Irrigation and Drainage," 1899; "Physics of Agriculture," 1901; "Tillage, Its Philosophy and Practice," "The Necessity and Practice of Drainage", in Cyclopedia of American Agriculture, 1907; "Drainage" and "Irrigation," in The Standard Cyclopedia of Modern Agriculture, (British) 1908.

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"To the ordinary farmer the title of this book is somewhat misleading. If he is not in an irrigating district, and has no wet lands, he will at once conclude, on seeing the title, that the subjects treated in the book do not concern him to the extent of $1.50. If, however, by chance he has the opportunity of reading the book he will change his opinion. The proper amount of water available at the right time is essential to successful or profitable farming in any country, and, therefore, Professor King opens his books with some general remarks on the importance of water; on the texture of the soil necessary to conserve the moisture; and follows it up with the report of some experiments showing the amount of water used by plants, which will be a surprise to the farmers who have not investigated the subject. The method by which the water is obtained by plants and exhaled; the remarkable way in which the plants themselves control the demand, economize water, so to speak; the mechanism by which the roots get hold of the moisture; the extent of the root surface; all these are treated in a wonderfully interesting way in this book, and are of all-absorbing interest to the man who is farming for dear life, and, if he is properly awake to the importance of the subject, will prove as interesting as a novel . . . We regard it as one of the most valuable contributions made to the science of agriculture in recent years."—Wallaces' Farmer.

"But although the author travels far and wide in search of examples and results in illustration of the principles which he advances, and so far introduces matter which is of great importance in the discussion of irrigation proper, yet the bulk of what he has written is full of instruction of the most practical character for the rent-paying farmer."—Manchester (England) Guardian.